ERDC/EL TR-02-32

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Effects of Increased Commercial Navigation Traffic on Freshwater Mussels in the Upper Mississippi River: Ten-Year Evaluation

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September 2002

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ERDC/EL TR-02-32
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Final report

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Prepared for U.S. Army Engineer District, St. Louis
St. Louis, MO 63103-2833

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Preface

In accordance with the Endangered Species Act, Section 7 Consultation, personnel from the U.S. Army Engineer District, St. Louis, and the U.S. Fish and Wildlife Service (USFWS) determined that studies should be conducted in the upper Mississippi River (UMR) to assess the effects of existing and projected future increased commercial navigation traffic on freshwater mussels including the endangered Higgins eye pearly mussel, *Lampsilis higginsi*. Concern had been expressed by the USFWS and other agencies that projected increases in traffic resulting from completion of the Melvin Price Locks and Dam, Second Lock Project, formerly known as Locks and Dam 26 at Alton, IL, could negatively affect freshwater mussels. In 1988, the St. Louis District contracted with the U.S. Army Engineer Waterways Experiment Station, now part of the Engineer Research and Development Center (ERDC), to initiate studies on traffic effects in the UMR. Sample sites were identified in 1988 and 1989, and studies continued annually until 1994. After this time they would be conducted every fifth year until 2040. This report describes results of studies conducted in 1999 at three mussel beds located in Pools 10, 14, and 24.

A five-person dive crew from Tennessee Valley Authority collected mussels for this project. Mr. Dan Ragland, St. Louis District, supplied maps and other background information. Assistance in the field was provided by Mr. Will Green, University of Southern Mississippi; Ms. Kathryn Barko, University of Wisconsin at Stevens Point; and Mr. Mark Farr, University of Georgia at Athens.

During the conduct of this study, Dr. Edwin A. Theriot was Director, Environmental Laboratory (EL), ERDC; Mr. Dave J. Tazik was Chief, Ecosystem Evaluation and Engineering Division, EL, ERDC; and Dr. Al Cofrancesco was Chief, Aquatic Ecology and Invasive Species Branch, EL.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL John W. Morris III, EN, was Commander and Executive Director.

This report should be cited as follows:

Miller, A. C., and Payne, B. S. (2002). "Effects of increased commercial navigation traffic on freshwater mussels in the upper Mississippi River: Ten-year evaluation," ERDC/EL TR-02-32, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

1 Introduction

Concern Over the Environmental Effects of Commercial Vessel Movement

In the United States, three projects are responsible for initiating concern over the environmental effects of commercial navigation traffic: the Tennessee-Tombigbee Waterway, a connecting link between the Tennessee and Tombigbee Rivers in Alabama and Mississippi; construction of a new lock in the Ohio River at Gallipolis between Ohio and West Virginia; and the lock replacement project in the Mississippi River near Alton, IL. Since the early 1980s, environmental groups and state conservation agencies have expressed concern over the environmental effects of vessel movement. As a result, there has been much speculation and discussion on this topic, mostly in the governmental or nonrefereed literature. These studies include: Virginia Polytechnic Institute and State University (1975); Academy of Natural Sciences of Philadelphia (1980); Berger Associates, Ltd. (1980); Sparks et al. (1979); U.S. Army Corps of Engineers (1980); Lubinski et al. (1980, 1981); Environmental Science and Engineering (1981, 1988); Kennedy, Harber, and Littlejohn (1982); Simons et al. (1981); Simons, Ghaboosi, and Chang (1987); Wuebben, Brown, and Zabilansky (1984); and Nielsen, Sheehan, and Orth (1986). However, after reviewing much of this information, Wright (1982) considered most of these to be speculative. Regardless, the increasing use of inland waterways to transport bulk commodities (Dietz et al. 1983), and the recent articles on impacts of waterway use in Europe (Brookes and Hanbury 1990, Haendel and Tittizer 1990), suggest that this issue will remain important well into the 21st century.

Background on the Melvin Price Locks and Dam

In the late 1980s, the U.S. Army Engineer District, St. Louis, initiated construction on the Melvin Price Locks and Dam to replace Locks and Dam 26 on the Mississippi River near Alton, IL. The new structure has two chambers, one 1200 ft (366 m) long for commercial tows, and a 600-ft (83-m) auxiliary lock for smaller craft. Since the original structure consisted only of a 600-ft lock and a smaller 360-ft (110-m) auxiliary lock, the new facility greatly reduced traffic congestion. Previously, delays up to 72 hr were common. Alton is at a critical segment of the waterway; 15 miles (24 km) north is the confluence of the Illinois

River, which leads through the Chicago Ship Canal to Lake Michigan, and 10 miles (16 km) south is the confluence of the Missouri River. The lock is 200 miles (322 km) upriver of the confluence of the Ohio River.

The replacement project will increase the capacity for commercial navigation traffic in the upper Mississippi River (UMR). This has the potential for increasing the number of tows using the upper river, although substantial increases were not noted during this study (see Figures 1-5). The U.S. Fish and Wildlife Service (USFWS) was concerned over the possible effects of increased commercial traffic on the endangered Higgins eye pearly mussel, *Lampsilis higginsi*. This species, although uncommon, is regularly collected in Pools 15 through 10 (and occasionally north and south of this river reach) (Havlik and Stansbery 1977). On 20 November 1987, the USFWS transmitted their "Biological Opinion" to the St. Louis District, which described possible physical and biological effects of commercial traffic. The Biological Opinion dealt primarily with possible effects of increased traffic on *L. higginsi*.

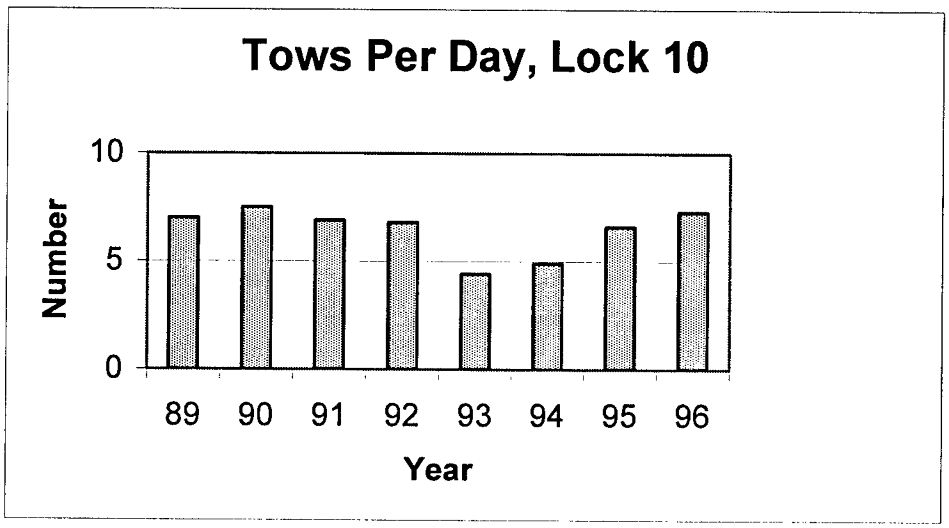

Figure 1. Number of tows per day (calculated for the navigation season) for Lock 10 on the UMR, 1989-96 (information from Water Resources Support Center, Navigation Data Center, Lock Performance Monitoring System)

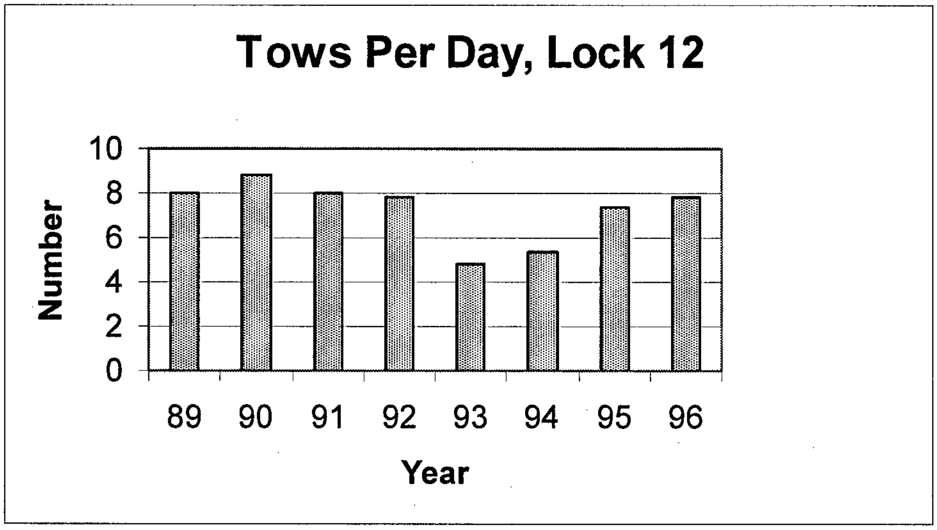

Figure 2. Number of tows per day (calculated for the navigation season) for Lock 12 on the UMR, 1989-96 (information from Water Resources Support Center, Navigation Data Center, Lock Performance Monitoring System)

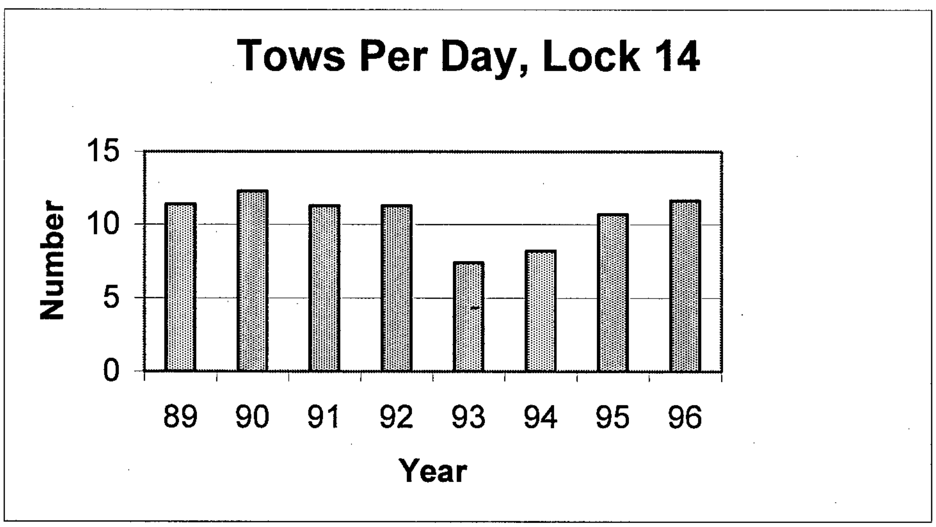

Figure 3. Number of tows per day (calculated for the navigation season) for Lock 14 on the UMR, 1989-96 (information from Water Resources Support Center, Navigation Data Center, Lock Performance Monitoring System)

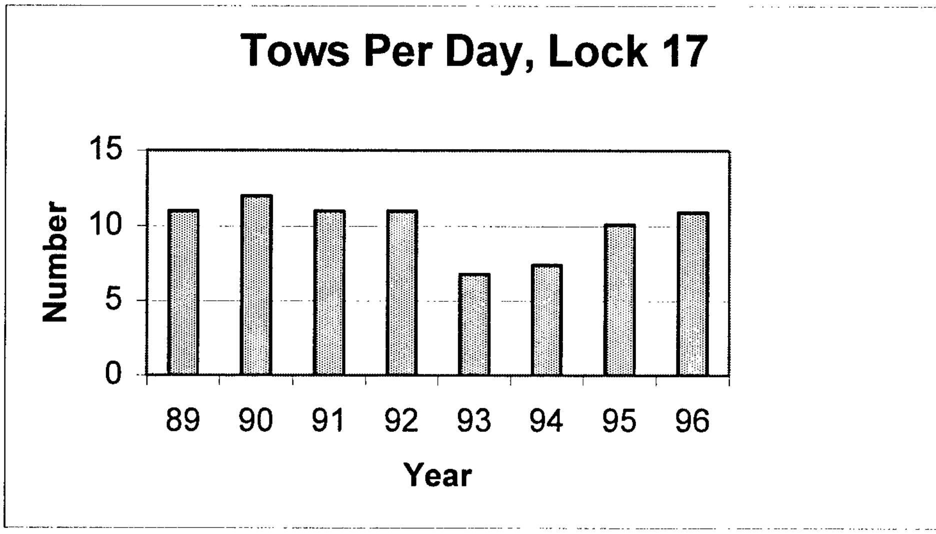

Figure 4. Number of tows per day (calculated for the navigation season) for Lock 17 on the UMR, 1989-96 (information from Water Resources Support Center, Navigation Data Center, Lock Performance Monitoring System)

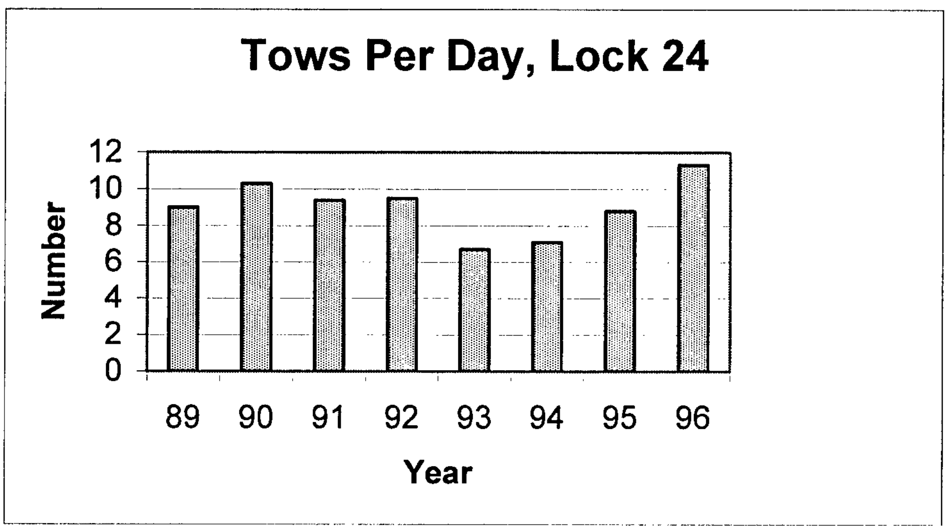

Figure 5. Number of tows per day (calculated for the navigation season) for Lock 24 on the UMR, 1989-96 (information from Water Resources Support Center, Navigation Data Center, Lock Performance Monitoring System)

Need to Monitor Mussels in the UMR

In accordance with the Endangered Species Act, Section 7 Consultation, personnel from the St. Louis District and the USFWS determined that a monitoring program should be initiated to assess the effects of projected traffic levels on freshwater mussels, including *L. higginsi*. The monitoring plan would be designed to obtain data on changes in water velocity and suspended solids near the substrate-water interface at dense and diverse mussel beds where *L. higginsi* was found. In addition, important biotic parameters such as species richness, species diversity, density, growth rate, and population structure of dominant mussel species were to be monitored. Data collected on common mussels would be used to determine whether commercial navigation traffic negatively affected *L. higginsi*. This surrogate species concept was used since it is difficult (and inappropriate) to obtain information on density, recruitment, and other biotic parameters for uncommon or endangered species. In addition to the USFWS, other agencies that participated in the development of this monitoring program included the U.S. Army Engineer Divisions, Lower Mississippi Valley and North Central; U.S. Army Engineer Districts, St. Paul and Rock Island; and selected state conservation agencies.

The purpose of this report is to present results obtained in 1999 at three mussel beds located in Pools 10, 14, and 24 of the UMR. Results are compared with data collected from 1988 to 1994.

A reconnaissance to choose sample sites and to conduct preliminary sampling was conducted in 1988 (Miller et al. 1990) and also in 1989 (Miller and Payne 1991). Previous reports on the UMR can be found in Miller and Payne (1992, 1993, 1994a, 1995a,b).

2 Study Design, Study Area, and Methods

Study Design

Physical studies were designed to obtain information on changes in water velocity and suspended solids near the substrate-water interface when vessels passed certain mussel beds in the UMR. Biological studies were designed to obtain important parameters such as species richness, species diversity, density, and population structure of dominant mussel species. Physical and biological data were collected at farshore experimental and nearshore reference sites within each mussel bed. Experimental sites were located close to the navigation channel and were affected by vessel passage. Reference sites were located some distance from the channel and were affected to a lesser extent by vessel passage.

Baseline studies took place from 1988-94 during a period when traffic levels were not expected to increase. After 1994, biological and physical data were to be collected every 5 years. This was to be done until traffic levels increased (as a result of completion of the Melvin Price Locks and Dam) by an average of one tow per day above 1990 levels. Studies would then resume at the original rate annually and continue until 2040, the economic life of the project. Summary information on studies conducted at each mussel bed appears in Tables A1 and A2, Appendix A.

A set of parameters was identified to evaluate effects of commercial navigation traffic on freshwater mussels. Results of the preliminary study (1988), and the 6 years (1989-94) of detailed study, provided baseline physical and biological information. Information obtained after this period would be compared with earlier results to make an assessment of negative effects. The parameters discussed below were used to determine if commercial navigation traffic negatively affects freshwater mussels.

Decrease in density of five common-to-abundant species

Density of common-to-abundant species was determined during the baseline period (1988-94). Negative effects will be assumed if there is a significant ($p < 0.1$) decline in density, sustained over each of at least two consecutive

sampling periods (i.e., a study year), for at least five common-to-abundant species.

Presence/absence of *L. higginsi*

During the baseline survey the degree of effort required to obtain a specific number of *L. higginsi* was determined. If after 1994 *L. higginsi* is not collected on two consecutive sampling periods using this same effort, it will be assumed that this species is declining.

Decrease in live-to-recently-dead ratios for dominant species

Live-to-dead ratios for common-to-abundant species were determined each study year. Negative effects will be assumed if there is a continual decrease in the live-to-recently-dead ratio for three consecutive sampling periods.

Loss of more than 25 percent of the mussel species

Total species richness (number of unionid species) was determined at each mussel bed during the baseline study period. Negative effects will be assumed if subsequent sampling sustained over two sampling periods reveals a loss of more than 25 percent of the mussel species known to occur at the bed.

No evidence of recent recruitment

Evidence of recent recruitment was determined for all species during the baseline period. No signs of recruitment for two consecutive sampling periods for five common-to-abundant species will represent a negative change.

Study Area

The UMR was once a free-flowing, braided, pool-riffle habitat with side channels, sloughs, and abandoned channels. This riverine habitat was altered as a result of passage of the Rivers and Harbors Act of 3 July 1930, which authorized the U.S. Army Corps of Engineers to construct a navigation channel with a minimum depth of 9 ft (2.7 m) and a minimum width of 300 ft (91.4 m). Development of this navigation channel, which included construction of locks, dams, dikes, wing dams, and levees, converted the river to a series of run-of-the-river reservoirs, characterized by relatively slow-moving water and extensive adjacent lentic habitats. Typically the upriver reaches of each pool in the UMR have comparatively high water velocity and coarse substratum, whereas the lower reach of each pool is more lake-like with deep, low-velocity water and fine-grained sediments (Eckblad 1981).

In 1988, preliminary biotic and physical data were collected at mussel beds in Pools 26, 25, 24, 19, 18, 17, 14, 10, and 7. In 1989, preliminary studies were conducted in Pools 12 and 13. Studies conducted during these years were used to determine if mussel beds identified from resource maps (Peterson 1984) were

suitable for detailed study. Based on information from these surveys, a list of mussel beds suitable for more detailed study was prepared.

Personnel of the St. Louis District, USFWS, and U.S. Army Engineer Research and Development Center (ERDC) participated in the final site selection process. Beds chosen for detailed study are located at the following river miles (RM):

Pool	RM
24	299.6 Right descending bank (RDB)
17	450.4 RDB
14	505.5 Left descending bank (LDB)
12	571.5 RDB
10	635.2 RDB main channel

Each bed is several miles long, and exact location of sampling sites can vary slightly from year to year. A brief description of the three locations sampled in 1999 appears below.

Pool 10

Near Prairie du Chien, WI, the UMR splits into an east and west or main channel (Figure 6). The east channel is slightly less deep and not as wide as the main channel, although the north end is navigable. Sediments in both the east and main channel consist of sand and silt with less than 5-percent gravel by weight. Numerous sloughs, aquatic plant beds, and islands characterize much of Pool 10 and this study reach. The study site for this monitoring program is in the west or main channel of the UMR. In this report, data collected in the main channel at nearshore and farshore sites are presented as well as data on zebra mussels from the east channel, 1999-2001.

Pool 14

An extensive mussel bed is located in the lower portion of Pool 14 on the LDB (Figure 7). This bed supports a dense and diverse assemblage of mussels, including *L. higginsi*. Substratum consists of silts, sand, and gravel.

Pool 24

The mussel bed in Pool 24 is located on the RDB approximately 1.5 miles (2.4 km) downriver of Lock and Dam 22 (Figure 8). Along the LDB are a series of wing dams that direct water across the channel and toward the mussel bed. Commercial traffic must move along the RDB when approaching or exiting the lock. Substrate consists of slab rock, coarse gravel, and sand. *Lampsilis higginsi* has never been found in Pool 24, although this bed contains a dense and diverse assemblage of mussels. This site was included so that data would be collected in a lower portion of the UMR that was outside the range of *L. higginsi*.

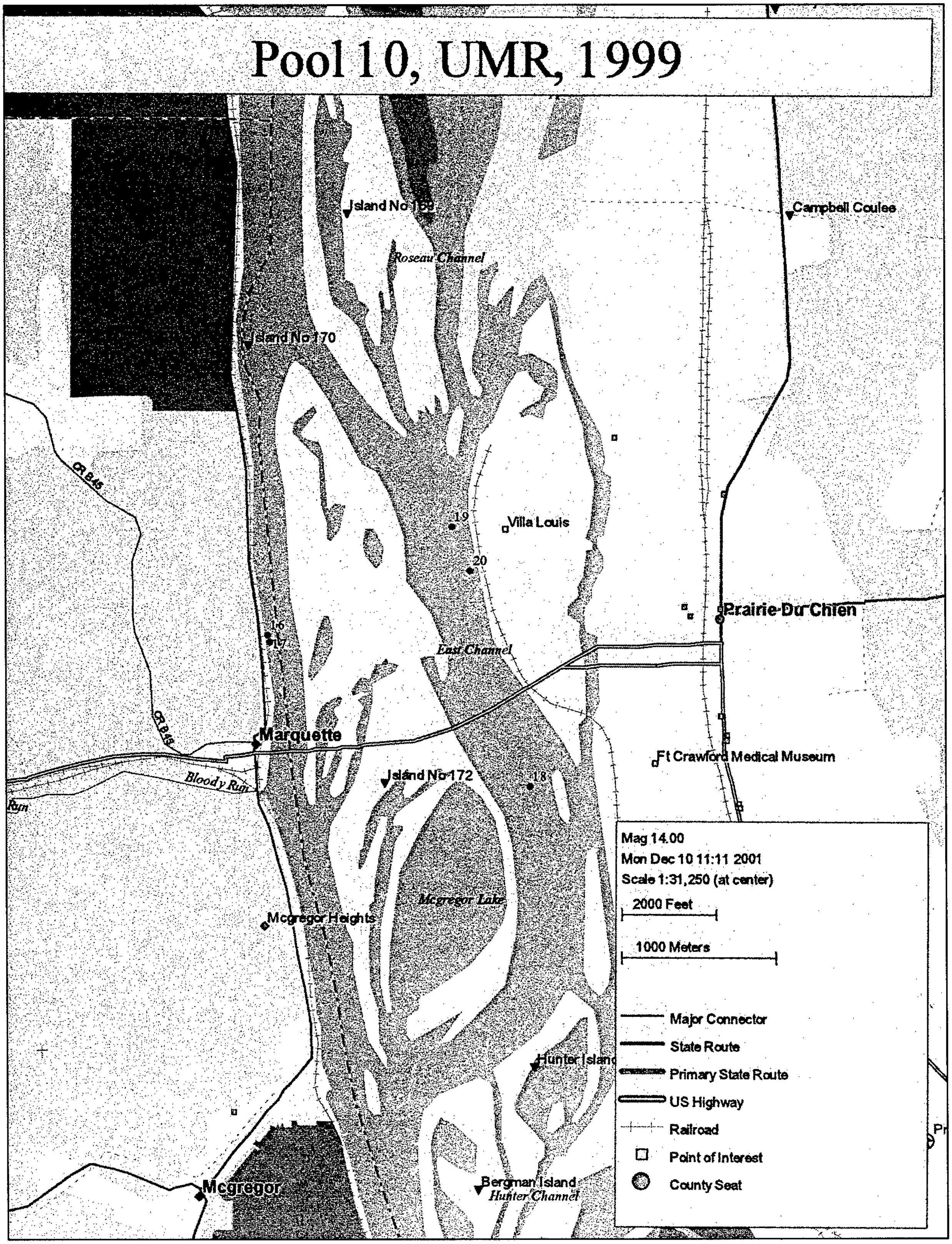

Figure 6. Location of sites in Pool 10. Sites north of Marguette (waypoints 16 and 17) are permanent for this study

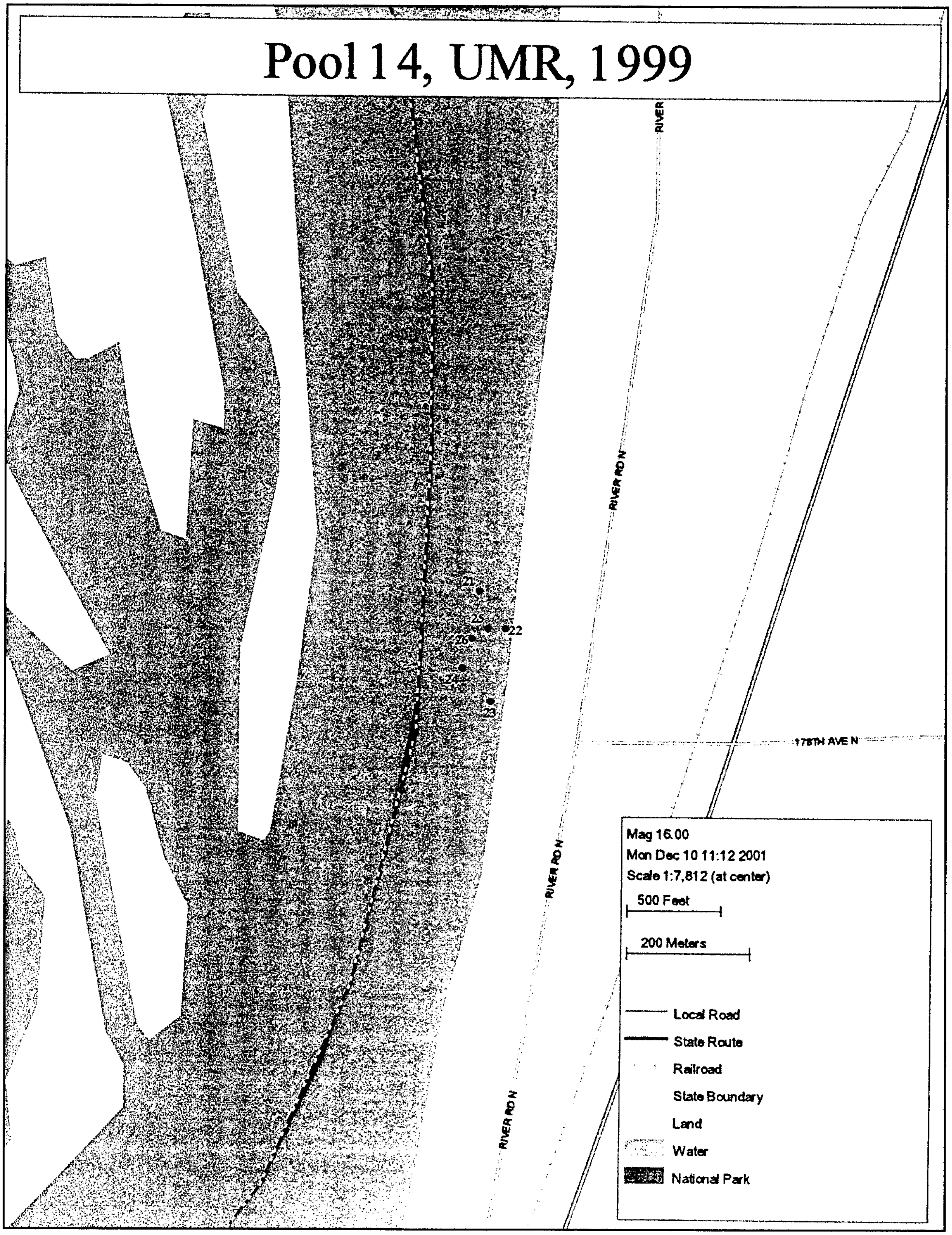

Figure 7. Location of sites in Pool 14

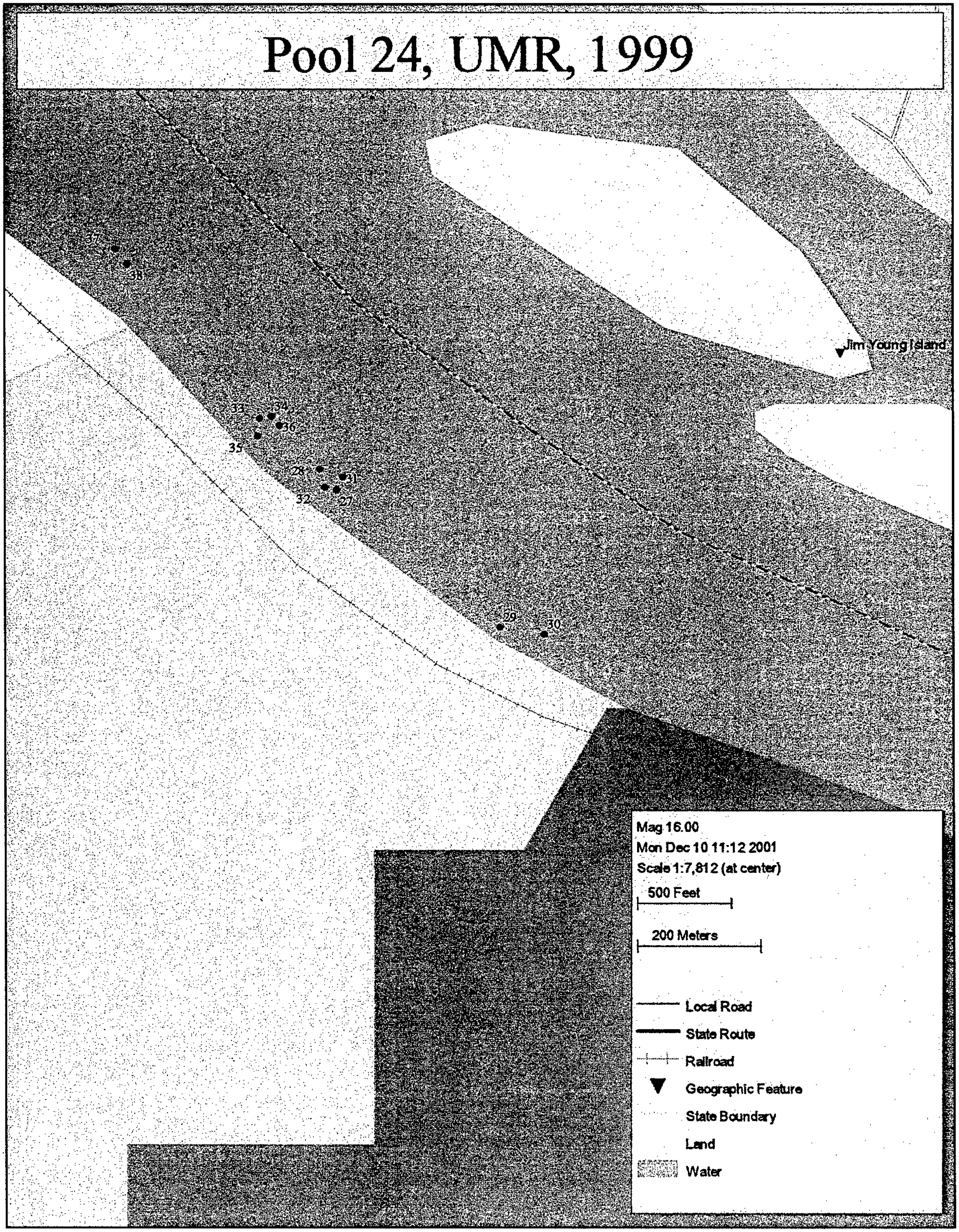

Figure 8. Location of sites in Pool 24

Methods

Preliminary reconnaissance

A diver equipped with surface air supply and communication equipment made a preliminary survey of each site before detailed studies began. He obtained information on substrate type, water velocity, and presence of mussels. A fathometer was used to measure water depth, and distance to shore was determined with an optical range finder.

Latitude and longitude for study sites were recorded with a hand-held global positioning system (GPS) Garmin GPS12XL Personal Navigator (Table 1, Figures 6-8). Typically, a waypoint was established at each site where the boat was anchored and samples were taken. Maps were produced from coordinates obtained in the field and information stored in *Street Atlas Version 6.0*. Based upon information provided by Garmin, Inc., there can be an error of approximately 5 to 100 m when using this equipment. Errors can also occur when waypoints are plotted on maps that are slightly out of date.

Qualitative collections

Two divers working simultaneously obtained qualitative samples. Divers were given 12 nylon bags and instructed to place about 5 mussels in the first 3 bags and about 20 mussels in the remaining 9 bags. Divers attempted to collect only live mussels, although occasionally dead shells were taken that were later discarded. Collecting was done mainly by feel since water visibility was poor. Mussels were brought to surface, identified, counted, and then returned to the river unharmed.

Quantitative sampling

At each nearshore or farshore site, ten 0.25-m^2 quadrat samples were obtained at each of three subsites separated by 5 to 10 m. At each subsite, quadrats were placed approximately 1 m apart and arranged in a 2 by 5 matrix. The diver removed all sand, gravel, shells, and molluscs within the quadrat. It usually took 5 to 10 min to clear the quadrat to a depth of 10 to 15 cm. All material was sent to the surface in a 20-L bucket, taken to shore, and sieved through a nested screen series (finest screen with apertures of 6.4 mm) and picked for live organisms. All bivalves were identified, and total shell length measured to the nearest 0.1 mm. All *L. higginsi* were returned to the river unharmed. Notes were made on the number of "fresh dead mussels" defined as dead individuals with tissue still attached to the valves. Nomenclature was consistent with Williams et al. (1993).

Table 1
Locations of Sample Sites, UMR, 1999 Study[1]

Date	Waypoint	Pool	Location	Total Quantitative Samples	Total Qualitative Samples	Latitude	Longitude
19 Jul	16	10	MC-NS	30	12	43.050764	91.177314
19 Jul	17	10	MC-FS	30	12	43.050353	91.177141
20 Jul	18	10	EC-BB	60		43.042078	91.15644
21 Jul	19	10	EC-TB	60		43.057002	91.1627
22 Jul	20	10	EC-RF	60		43.054481	91.161273
23 Jul	21	14	NS	30	2	41.701664	90.311759
23 Jul	22	14	FS	30	2	41.701119	90.311247
24 Jul	N/D	14	NS		2		
24 Jul	23	14	NS		2	41.700045	90.311531
24 Jul	24	14	NS		2	41.700533	90.312086
24 Jul	25	14	FS		2	41.701119	90.311585
24 Jul	26	14	FS		2	41.700972	90.311901
25 Jul	27	24	NS	30	2	39.618153	91.229718
25 Jul	28	24	FS	10	2	39.618448	91.23004
26 Jul	29	24			2	39.616163	91.226639
26 Jul	30	24			2	39.616061	91.225802
26 Jul	31	24			2	39.618335	91.229594
26 Jul	N/D	24			2		
26 Jul	32	24	FS	20	2	39.618191	91.229938
27 Jul	33	24			2	39.619172	91.231172
27 Jul	34	24			2	39.619204	91.230952
27 Jul	35	24			2	39.618925	91.231209
27 Jul	36	24			2	39.619081	91.230801
27 Jul	37	24			6	39.621618	91.233897
27 Jul	38	24			8	39.621404	91.233666

[1] MC = main channel, EC = east channel, NS = nearshore, FS = farshore, BB = below bridge, TB = turning basin, RF = reference site, N/D = no data.

3 Results and Discussion

Summary of 1999 Studies

Twenty-six species of bivalves, including the Asian clam, *Corbicula fluminea,* were collected at the three locations in the UMR using qualitative methods (Table 2). The fauna was dominated by *Amblema plicata*; this species comprised more than 60 and 40 percent of the fauna in Pools 10 and 14, respectively. *Ellipsaria lineolata* was the dominant freshwater mussel at the mussel bed in Pool 24, although it was only slightly more common than *A. plicata.* The endangered *L. higginsi* was found in Pool 10 (1.72 percent) and Pool 14 (2.44 percent), but not in Pool 24, which is outside its range.

Using quantitative methods, nearly 300 individuals and 23 species of mussels were collected at the three locations in the UMR during the 1999 survey (Table 3). Mean total density varied from a low of 0.6 (standard deviation = 1.9) in Pool 14 to a high of 10.8 (standard deviation = 7.6) in Pool 10 (Table 4). *Amblema plicata* dominated numerically at all sites in the UMR, although dominance was shared by *Obliquaria reflexa* and *Ellipsaria lineolata* at Pool 24 (Table 3). A reduced density at Pool 10 and Pool 14 was the result of high levels of zebra mussels (see below).

Data collected using qualitative and quantitative methods appears in Appendices B and C, respectively.

Introduction and Spread of Zebra Mussels, *Dreissena polymorpha,* in the UMR

The first report of *D. polymorpha* in North America was from Lake St. Clair in June 1988 (Hebert, Muncaster, and Mackie 1989; Roberts 1990). By late summer 1989, zebra mussels had spread downstream into the Detroit River, Lake Erie, Niagara River, and western Lake Ontario (Griffiths, Kovalak, and Schloesser 1989). By late September 1990, zebra mussels had spread through Lake Ontario and down the St. Lawrence River to Massena, NY. In June 1991, biologists from the Illinois Natural History Survey found adult zebra mussels at Illinois RM 50, 60, and 110 (Moore 1991, Sparks and Marsden 1991).

Table 2
Percent Composition of Freshwater Bivalves Collected at Three Locations in the UMR, 1999, Using Qualitative Sampling Methods

Species	Pool 10 WP 12, 13	Pool 14 WP 21-26	Pool 24 WP 28-38
A. plicata	62.01	43.09	30.46
E. lineolata	0.00	0.27	31.80
O. reflexa	0.49	0.27	15.06
Q. quadrula	6.37	9.21	5.94
M. nervosa	7.60	8.40	2.68
Q. pustulosa	1.96	7.05	3.60
L. recta	4.90	10.03	0.50
L. cardium	3.43	8.13	1.17
O. olivaria	0.00	0.27	3.60
F. flava	2.70	1.90	1.17
L. fragilis	0.98	0.27	1.67
L. complanata	0.74	3.79	0.00
L. higginsi	1.72	2.44	0.00
A. confragosus	2.21	0.81	0.08
Q. nodulata	0.00	1.08	0.67
Q. metanevra	0.00	0.00	0.92
P. grandis	0.49	2.17	0.00
E. dilatata	2.45	0.00	0.00
T. truncata	0.00	0.00	0.33
P. coccineum	0.98	0.00	0.00
A. ligamentina	0.00	0.81	0.00
A. suborbiculata	0.74	0.00	0.00
P. alatus	0.25	0.00	0.08
C. fluminea	0.00	0.00	0.08
F. ebena	0.00	0.00	0.08
L. teres	0.00	0.00	0.08
Total species	17	17	19
Total Individuals	408	369	1195

Note: WP = waypoint.

Table 3
Percent Composition of Freshwater Bivalves at Three Locations in the UMR, 1999, Using Quantitative Sampling Methods

Species	**Pool 10** WP 16,17	Pool 14 WP 21,22	Pool 24 WP 27, 28, 32	Total
A. plicata	70.37	33.33	26.77	50.67
O. reflexa	1.23	0.00	21.26	9.73
E. lineolata	0.00	0.00	21.26	9.06
M. nervosa	6.17	22.22	1.57	4.70
Q. quadrula	1.85	22.22	7.09	4.70
O. olivaria	0.00	0.00	8.66	3.69
L. recta	4.32	0.00	0.00	2.35
L. fragilis	1.23	0.00	3.94	2.35
E. dilatata	3.70	0.00	0.00	2.01
F. flava	2.47	0.00	1.57	2.01
Q. pustulosa	1.85	0.00	2.36	2.01
L. cardium	1.23	0.00	1.57	1.34
S. undulatus	1.85	0.00	0.00	1.01
P. coccineum	1.23	0.00	0.00	0.67
L. complanata	0.00	22.22	0.00	0.67
T. truncata	0.00	0.00	1.57	0.67
A. ligamentina	0.62	0.00	0.00	0.34
L. higginsi	0.62	0.00	0.00	0.34
A. confragosus	0.62	0.00	0.00	0.34
L. siliquoidea	0.62	0.00	0.00	0.34
Q. nodulata	0.00	0.00	0.79	0.34
L. recta	0.00	0.00	0.79	0.34
T. donaciformis	0.00	0.00	0.79	0.34
Total individuals	162	9	127	298
Total species	16	4	14	23
% Species < 30 mm	6.25	0	6.3	
% Individuals < 30 mm	0.62	0	35.7	
Species diversity	1.33	1.37	2	
Evenness	0.48	0.99	0.76	
Menhinick's index	1.26	1.33	1.24	

Table 4
Summary of Density Data from Three Locations in the UMR, 1999

Subsite Number	No. of Samples	Average No./m^2	STD[1]
Pool 10, Waypoints 16, 17			
1	10	15.2	7.7
2	10	8.8	9.4
3	10	9.6	6.9
4	10	9.2	6.0
5	10	9.6	6.9
6	10	12.4	8.1
Total	60	10.8	7.6
Pool 14, Waypoints 21, 22			
1	10	0.0	0.0
2	10	0.8	1.7
3	10	0.8	1.7
4	10	1.6	3.9
5	10	0.4	1.3
6	10	0.0	0.0
Total	60	0.6	1.9
Pool 24, Waypoints 27, 28, 32			
1	10	0.8	1.7
2	10	1.2	1.9
3	10	10.0	11.2
4	10	22.8	14.0
5	10	7.2	8.0
6	10	8.8	5.9
Total	60	8.5	10.9

[1] STD - standard deviation.

By early January 1993, zebra mussels had spread throughout most of the inland waterway system. They probably reached upriver sites on hulls of commercial navigation vessels (Keevin, Yarbrough, and Miller 1992). They were found in the lower Mississippi River as far south as Vicksburg, MS, and in the UMR near St. Paul, MN (*Dreissena polymorpha Information Review* 1992).

In 1999, mean density of zebra mussels was approximately 1,000 and 1,400 individuals/m^2 in Pools 10 and 14, respectively (Figure 9). Mean density at the Pool 24 site was much less, approximately 100 individuals/m^2. A more complete data set, which follows the density of zebra mussels nearly every year since 1992

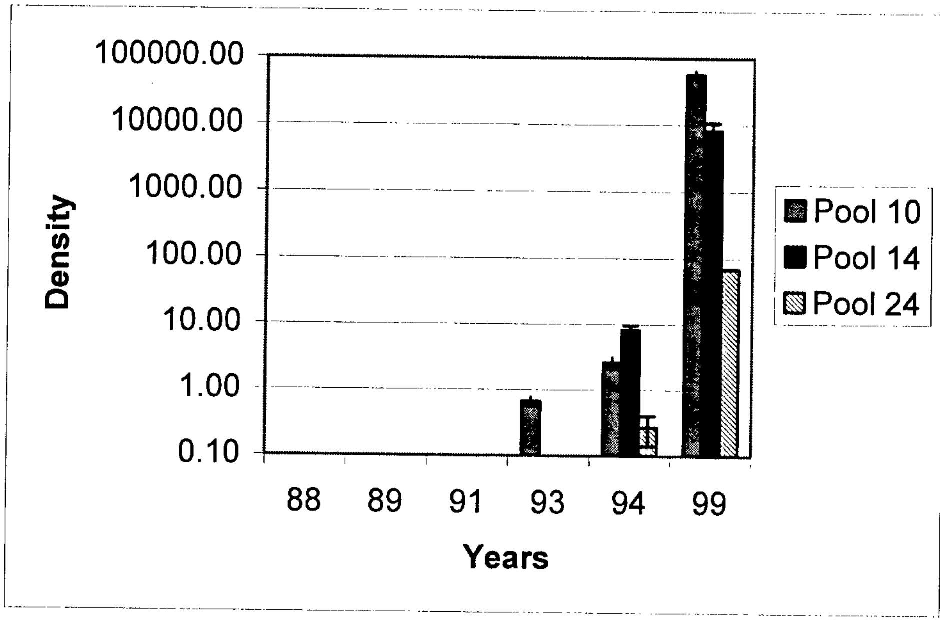

Figure 9. Density (individuals/m^2) plus standard error of the mean for *D. polymorpha* at study sites in three pools, UMR, 1988-94 and 1999

in the east channel of the UMR, appears in Figure 10. Sites in the east and west (or main channel) are less than 2 km apart and very similar in overall habitat characteristics. Densities are approximately the same at both locations, although the east channel is slightly more depositional and, therefore, slightly more suitable for zebra mussels. At the site in the east channel, zebra mussel densities increased rapidly to about 10,000/m^2 in 1996, and then vacillated around that value for several years (Figure 10).

Effects of high densities of zebra mussels on native mussels in this country and Europe have been thoroughly documented (Lewandowski 1976, Nalepa 1994). Zebra mussels certainly have adverse effects on native mussels, unlike the case of the Asiatic clam, *C. fluminea*, where sustained co-existence with native mussels has been documented in the lower Ohio River (Miller and Payne 1994b). As will be described below, effects of increased numbers of zebra mussels have completely masked any impacts of increased traffic, if any, in the UMR.

Temporal Trends in Parameters that Characterize the Relative Health of Mussel Beds

The following section deals with the criteria that were used to monitor the health of mussel beds in the UMR.

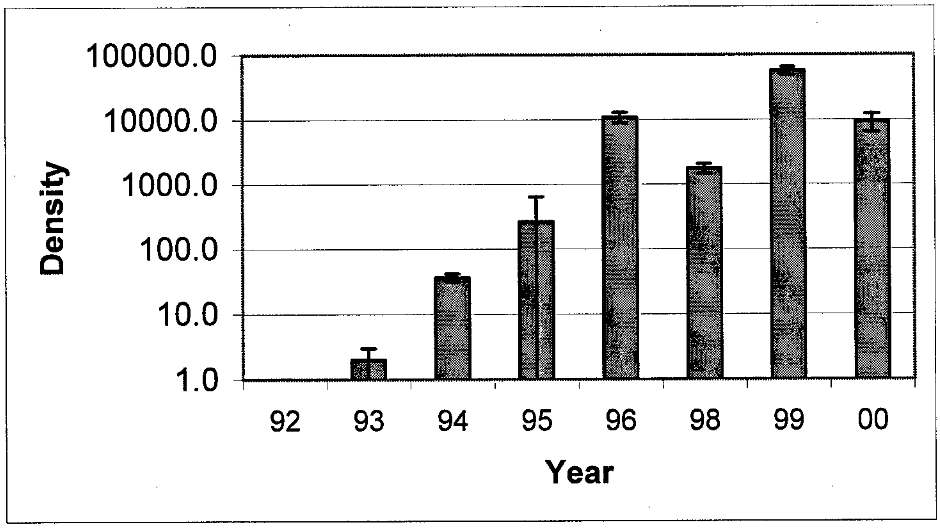

Figure 10. Density (individuals/m^2) plus standard error of the mean for *D. polymorpha* in the east channel of the UMR, Pool 10, RM 635.2, 1992-2000

Decrease in density of five common-to-abundant species

Using information from the first 5 years of study (Miller and Payne 1996), 24 comparisons among densities of abundant species were made. These included individual species, or else total mussels, at all of the five study sites. There were seven density declines (three were significant at the 0.1 level), and there were five density increases (two were significant at the 0.1 level). For 12 comparisons, there were no trends, either positive or negative.

Changes in mean density for the total mussel assemblage declined greatly between 1994 and 1999 at all three mussel beds (Figures 11-13). Variation among years was notable; for example, in 1989 mean density exceeded all other years in Pools 10 and 24 (Figures 11 and 13, respectively). Regardless, the density at all locations was significantly less in 1999 than during any previous year. A more complete data set, taken in the east channel of the Mississippi River near Prairie du Chien, WI, further illustrates effects of zebra mussels on native species (Figure 14).

Presence/absence of *L. higginsi*

Based on results of the first 5 years of this study (Miller and Payne 1996), the range in abundance of *L. higginsi* at these study sites varied from a low of 0.09 percent (quantitative samples) in 1989 at Pool 14 to 1.72 percent (qualitative samples) in 1988 at Pool 10. *Lampsilis higginsi* was never collected at the mussel bed in Pool 24, which is outside its range. Negative effects would be assumed if *L. higginsi* were not collected during two consecutive sampling periods. When this criterion was evaluated in the previous study (Miller and Payne 1996), there were no negative effects at beds in Pools 10 and 12.

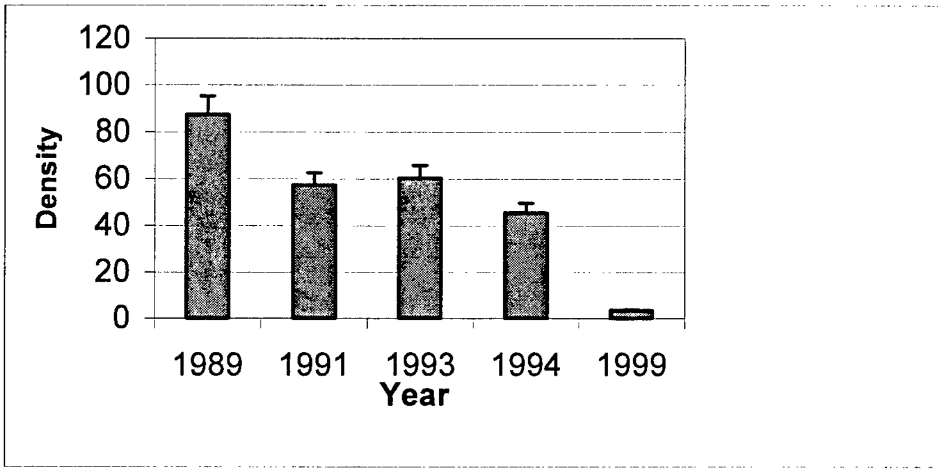

Figure 11. Mean unionid density (individuals/m^2) in the east channel of the UMR, Pool 10, RM 635.2, 1989-99

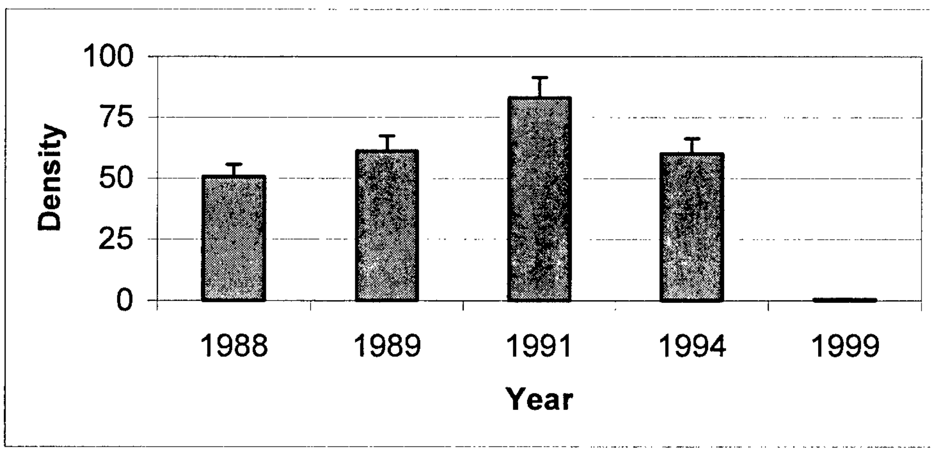

Figure 12. Mean unionid density (individuals/m^2) at RM 504.8, Pool 14 of the UMR, 1988-99

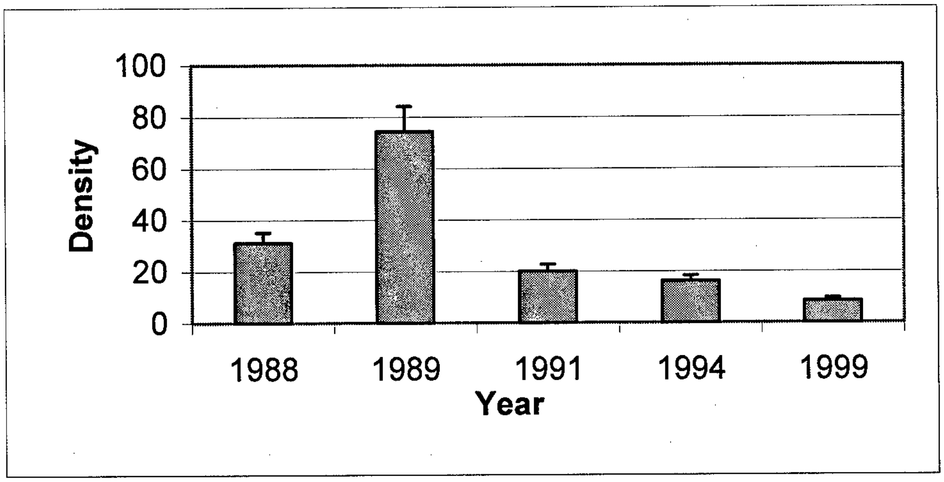

Figure 13. Mean unionid density (individuals/m^2) at RM 299.6, Pool 24 of the UMR, 1988-99

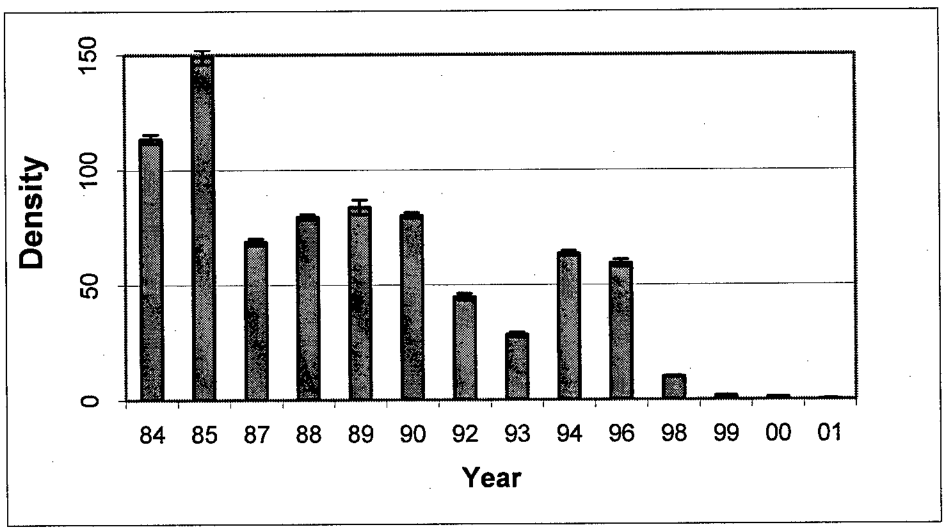

Figure 14. Mean unionid density (individuals/m^2), east channel of the UMR, Pool 10, RM 635.2, 1984-2001

No *L. higginsi* were collected using either qualitative or quantitative methods in Pool 14 during 1999 (Table 5). However, in Pool 10, main channel, this species was obtained using both qualitative and quantitative methods. Although zebra mussels in Pool 10 negatively affected the native mussels, living *L. higginsi* were still collected at this location in 1999 (Table 5). It is apparent that zebra mussels have affected total mussel density in the UMR, but not specifically *L. higginsi*.

Table 5
Number of *L. higginsi* Taken in Qualitative and Quantitative Samples in the UMR, 1988-99

Year	Quantitative Samples			Qualitative Samples		
	Total Mussels	*L. higginsi*		Total Mussels	*L. higginsi*	
		Total	%		Total	%
Pool 24, RM 299.6						
1988	78	0	0.00	326	0	0.00
1989	1143	0	0.00	648	0	0.00
1991	301	0	0.00	465	0	0.00
1992	107	0	0.00	184	0	0.00
1994	243	0	0.00	390	0	0.00
1999	127	0	0.00	1195	0	0.00
Pool 14, RM 504.8						
1988	253	1	0.4	734	8	1.09
1989	1131	1	0.09	961	5	0.52
1991	1247	6	0.49	815	6	0.74
1992	800	2	0.25	386	3	0.78
1994	903	4	0.44	789	6	0.76
1999	9	0	0.00	369	0	0.00
Pool 10, RM 635.2 - Main Channel						
1988	845	2	0.24	699	12	1.72
1989	1616	11	0.68	212	0	0.00
1991	861	2	0.23	690	4	0.58
1992	700	3	0.43	376	1	0.27
1993	905	4	0.11	404	1	0.25
1994	680	1	0.15	--	--	--
1999	162	1	0.62	408	7	1.72

Decrease in live-to-recently-dead ratios for dominant species

The criterion for this parameter stated that negative effects would be assumed if there were a continual decrease in the ratio of live-to-recently-dead organisms for three consecutive sampling periods. During the first 5 years, this criterion was easily met; recently dead mussels were rarely collected and always made up less than 1 percent of the sample.

In 1996, between 10 and 25 percent of the dead shells appeared to be the result of fairly recent mortality. Percentages of dead native mussels increased in subsequent years; by 2001, virtually all of the native mussels were dead. Death did not occur at any specific year, but took place gradually starting in 1996 and continuing for the next 5 years. Certainly this criterion was not met; negative effects can be assumed since the live-to-recently-dead ratio decreased substantially. However, this mortality was the result of zebra mussels, and not commercial navigation traffic.

Loss of more than 25 percent of the mussel species

This criterion stated that negative effects would be assumed if there was a loss, sustained for two consecutive sampling periods, of over 25 percent of existing mussel species. For mussel beds that support 20 to 32 species, this would require a sustained loss of 5 to 8 species. A complete species list for each year at each bed, which includes total individuals and total species collected, appears in Appendix D, Tables D1-D3.

Based on the first 5 years of study (Miller and Payne 1996), the criterion for species richness was met at each bed; no bed experienced a sustained loss of any species. There were considerable interbed differences in species richness, brought about by local physical and hydraulic conditions. Menhinick's index and Shannon's diversity index were variable among years; however, no specific negative or positive trends were noted.

The total number of species and individuals collected using qualitative and quantitative methods for each of the three sampling locations in 1999 appear in Tables 2 and 3, respectively. Number of individuals and species of mussels collected since the late 1980s using qualitative (Figures 15-17) and quantitative methods (Figures 18-20) illustrate that these numbers have remained fairly constant. Species collected using quantitative methods in Pool 14 do exhibit a decline (Figure 19), although this location could be considered an exception. Obviously, the density of mussels has decreased, but the number of species present, given enough searching, has remained approximately the same.

Evidence of recent recruitment

It was determined that if no evidence of recent recruitment was observed for five common-to-abundant species for two consecutive sampling periods, then negative effects would be assumed. Based upon results from 1988 to 1994, it was determined that there was ample recent recruitment for UMR populations (Miller and Payne 1996).

Conversely, in 1999, no evidence of mussel species with at least one individual less than 30 mm total shell length was found in Pool 14, and numbers in Pool 10 were greatly reduced (Figure 21). Evidence of recent recruitment in Pool 24 was similar to that of previous years.

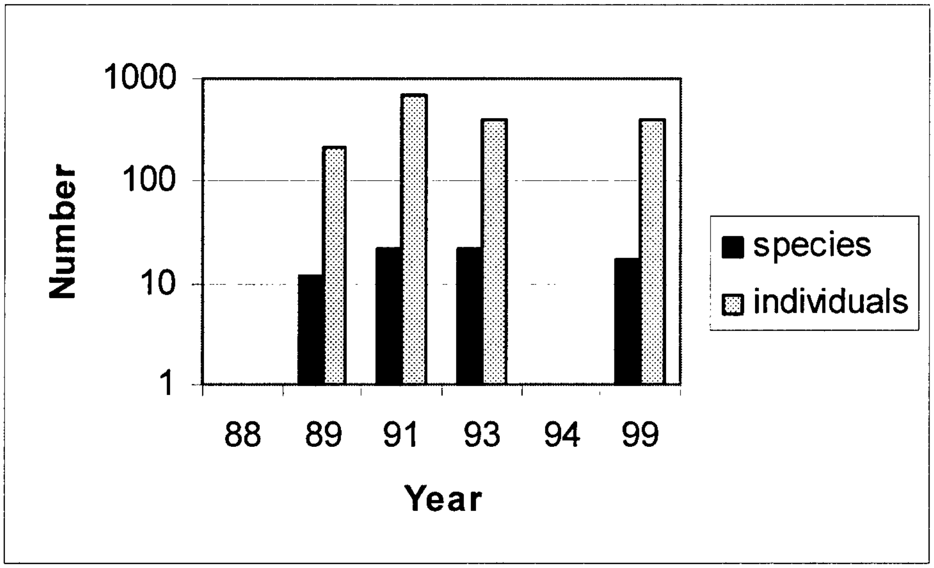

Figure 15. Total number of unionid species and individuals collected in qualitative samples in the main channel of the UMR, Pool 10, RM 635.2

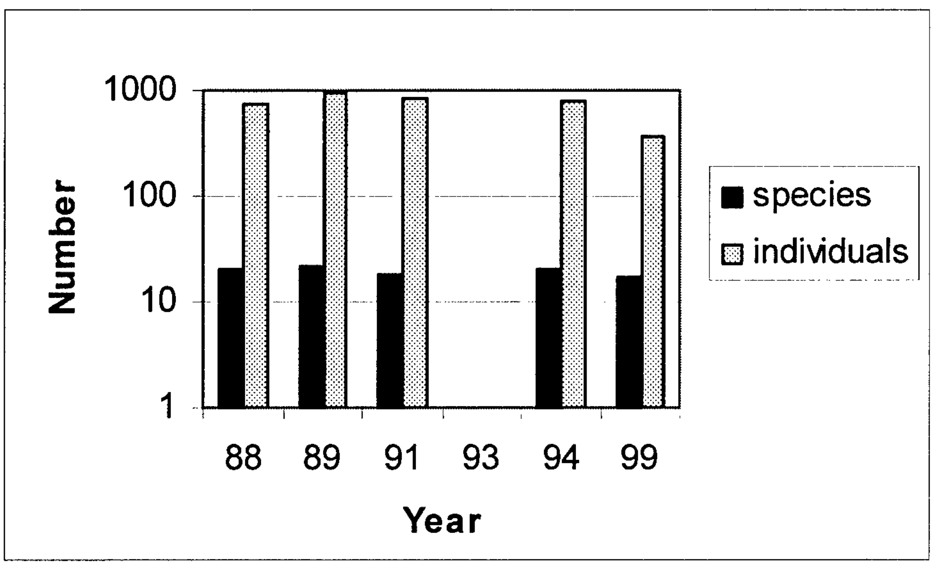

Figure 16. Total number of unionid species and individuals collected in qualitative samples in the UMR, Pool 14, RM 504.8

In 1999, no individual mussels with less than 30 mm in total shell length were found in Pool 10, and numbers in Pools 14 and 24 were greatly reduced (Figure 22). A more complete data set for recent recruitment appears in

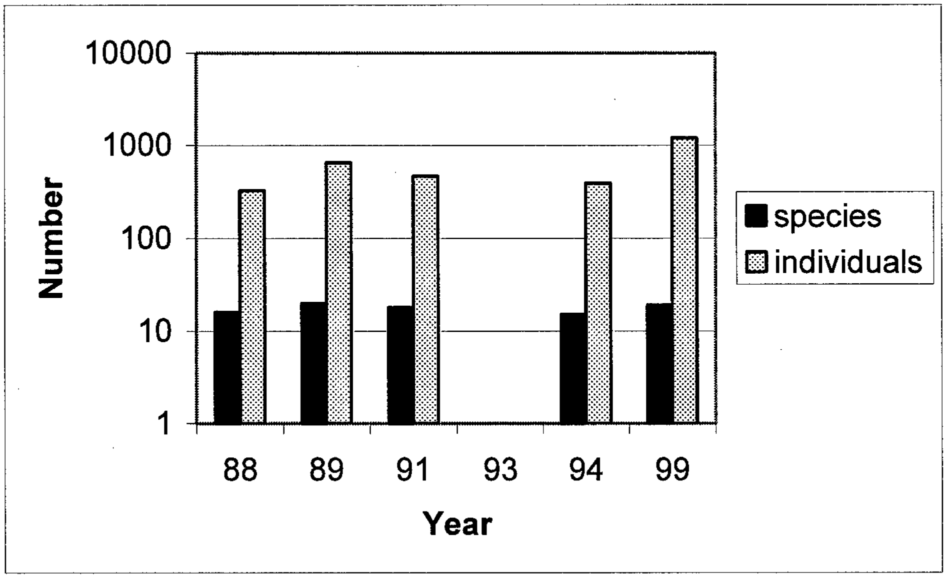

Figure 17. Total number of unionid species and individuals collected in qualitative samples in the UMR, Pool 24, RM 299.6

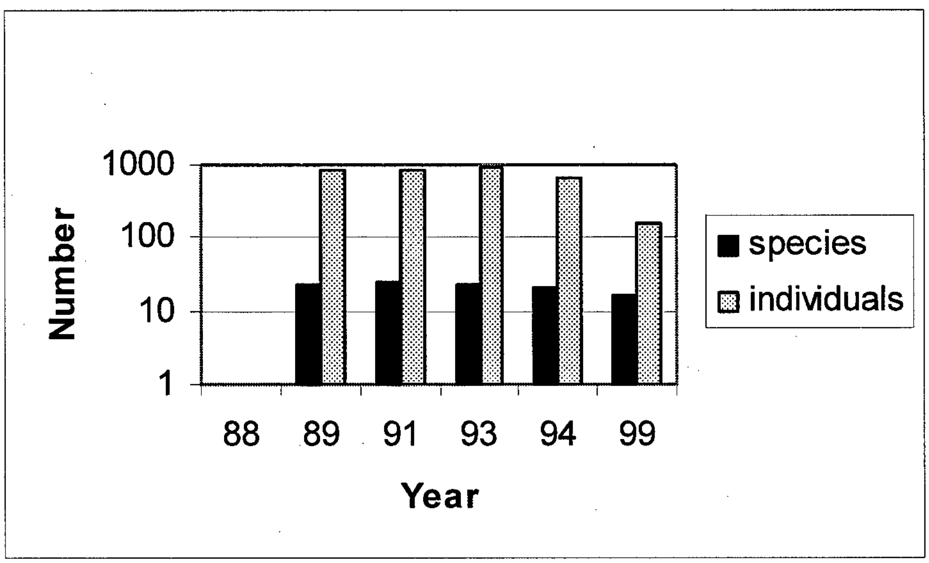

Figure 18. Total number of unionid species and individuals collected in qualitative samples in the UMR, Pool 10, RM 635.2

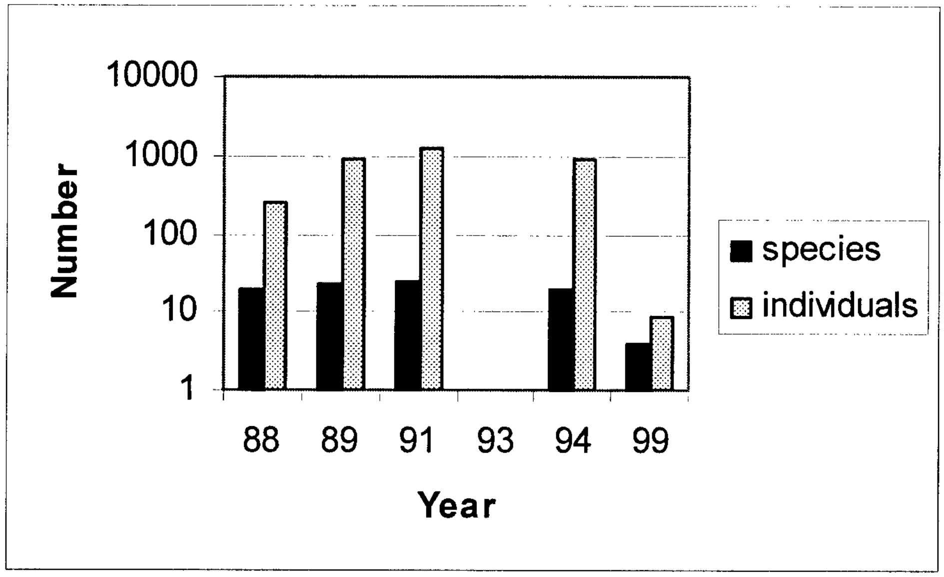

Figure 19. Total number of unionid species and individuals collected in qualitative samples in the UMR, Pool 14, RM 504.8

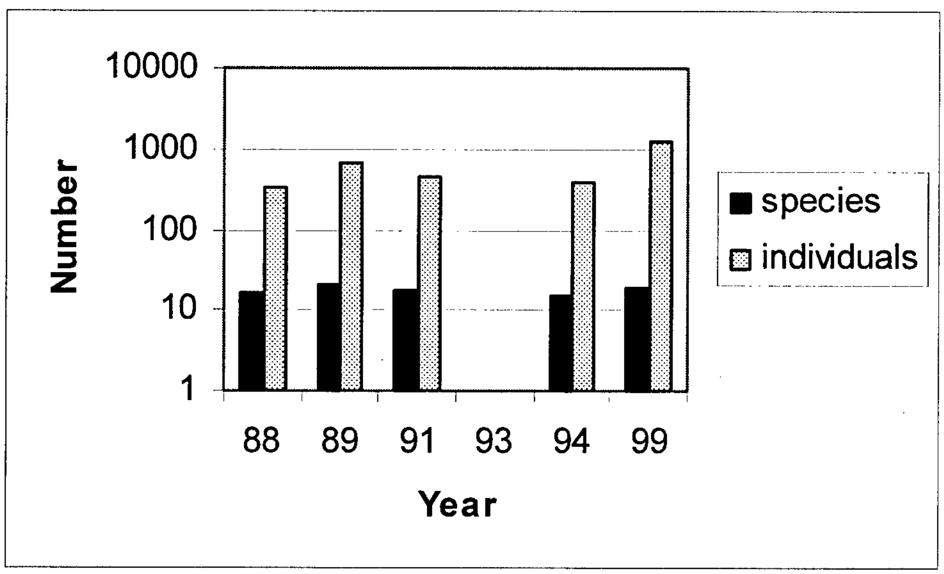

Figure 20. Total number of unionid species and individuals collected in quantitative samples in the UMR, Pool 24, RM 299.6

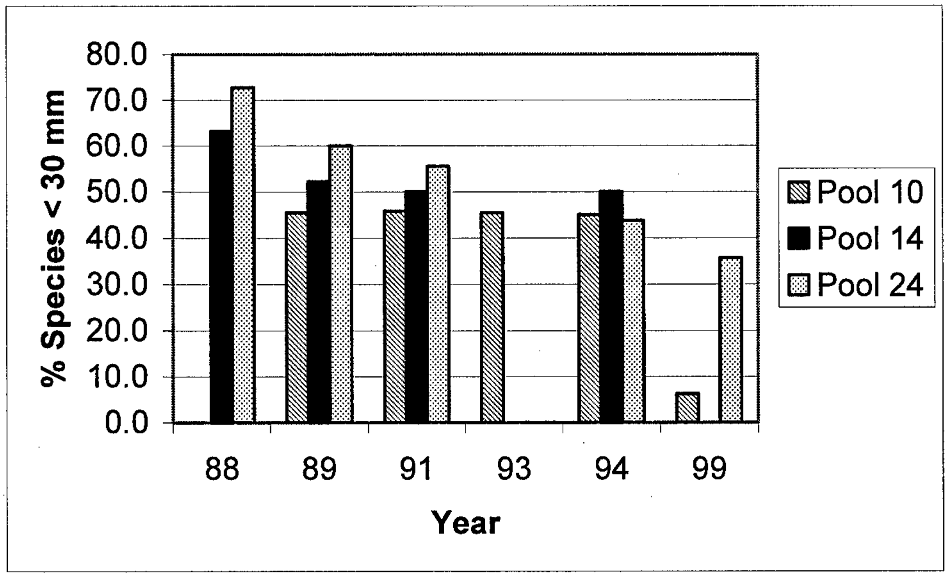

Figure 21. Percentage of total unionid species with at least one individual <30 mm total shell length at three locations in the UMR, 1988-1999

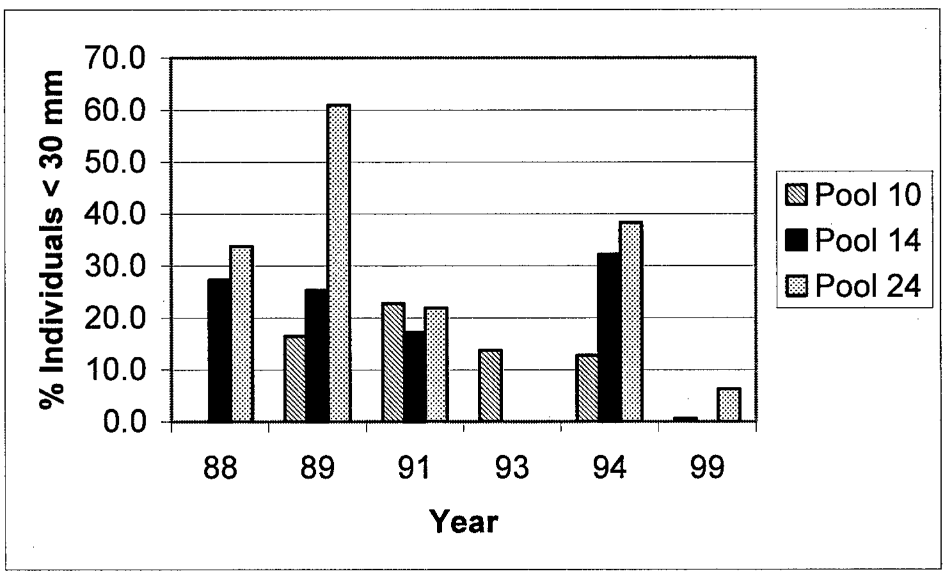

Figure 22. Percentage of total unionids, all species combined, <30 mm total shell length at three locations in the UMR, 1988-1999

Figures 23 and 24 in the east channel of the UMR, located less than 2 km from the west channel site. Virtually no recent recruitment was found, either in terms of species with at least one live individual present, or number of small individuals collected, for 1999-2001.

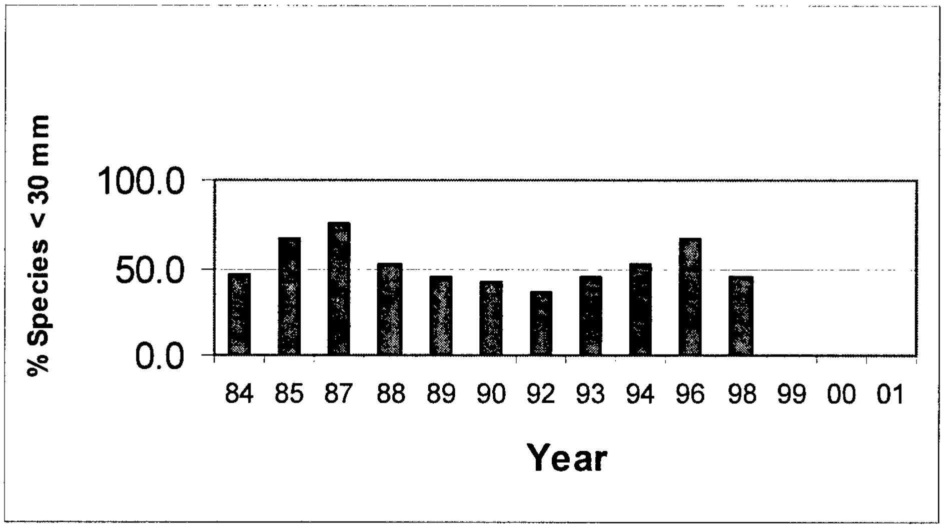

Figure 23. Percentage of total unionid species with at least one individual <30 mm total shell length at the reference site in the east channel of the UMR, Pool 10, RM 635.2, 1984-2001

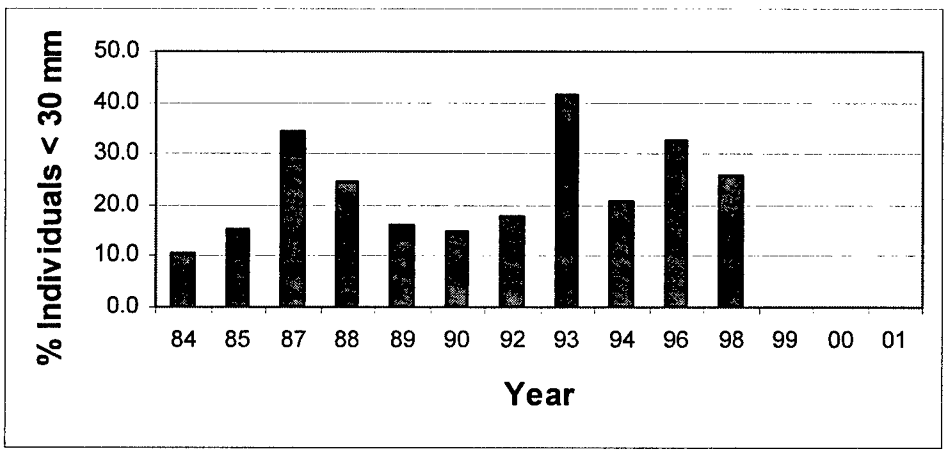

Figure 24. Percentage of total unionids, all species combined, <30 mm total shell length at the reference site in the east channel of the UMR, RM 635.2, Pool 10, 1984-2001

4 Summary and Conclusions

In 1988, the St. Louis District requested that the ERDC initiate studies to evaluate biological and physical consequences of commercial navigation traffic in the UMR. A moving commercial vessel produces a brief period of turbulence, increased water velocity, and elevated suspended solids caused by propeller wash, water displacement, and hull friction. These cyclic disturbances could interfere with feeding, water circulation, or otherwise damage freshwater mussels, especially the endangered *L. higginsi*. Freshwater mussels dominate the benthic biomass in most large rivers in the United States. Their sedentary lifestyle and reliance on suspended particulate organic matter as food makes them particularly susceptible to turbulence, sedimentation, and fluctuating water levels.

Preliminary studies were initiated in 1988, and detailed studies began in 1989 and continued through 1994. After 1994, studies were to be conducted every fifth year. In 1999, studies were conducted at three of the five mussel beds; these were located in Pools 10, 14, and 24. Divers used quantitative and qualitative methods to collect mussels to assess density, species richness, species diversity, evidence of recent recruitment, presence of *L. higginsi*, as well as relative species abundance and occurrence of mussels.

Following an evaluation of the first 5 years of study, it was concluded that there were no significant changes in the biotic criteria chosen to monitor the health of these mussel beds (Miller and Payne 1996). Results of studies conducted in 1999 were compared with results of the first 5 years. Based upon 1999 data, it was concluded that there were no changes in numbers of *L. higginsi*, or the total number of species present at these beds. There were, however, significant changes in total mean mussel density, ratios of live-to-dead mussels, and evidence of recent recruitment. These changes were not related to navigation traffic, which had not increased since 1990 (Figures 1-5), but rather to introduction and spread of the nonindigenous zebra mussel. Densities of this species increased from less than 100 in 1993 to approximately 10,000 individuals/m^2 by 1999.

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Appendix A
Background Information on the Survey

Table A1
Summary of Biological and Physical Studies Conducted for the Navigation Traffic Effects Study, Upper Mississippi River, 1988-99

Pool	RM	Year							
		88	89	90	91	92	93	94	99
24	299.6	Qual	Qual		Qual		ND	Qual	Qual
		Quant	Quant		Quant		ND	Quant	Quant
					Growth			Growth	
					Phys				
17	450.4	Qual		Qual		Qual		Qual	
		Quant		Quant		Quant		Quant	
				Growth					
				Phys					
14	504.8	Qual	Qual		Qual		ND	Qual	Qual
		Quant	Quant		Quant		ND	Quant	Quant
			Growth						
			Phys		Phys				
12	571.5		Qual	Qual		Qual		Qual	
				Quant		Quant		Quant	
				Growth					
				Phys					
10	635.2 MC	Qual	Qual		Qual		Qual	Qual	Qual
			Quant		Quant		Quant	Quant	Quant
			Growth						
			Phys		Phys				

Notes:

Precise river miles can differ in previous reports since exact location can vary slightly (0.1 to 0.4 km) each year.

Quant = Quantitative samples.

Qual = Qualitative samples.

Growth = Marked mussels were placed for analysis of rate of growth.

Phys = Physical studies such as measures of water velocity and total suspended solids following passage of a commercial vessel.

MC = Main channel.

ND = No data because of high water in 1993.

Table A2
Summary of Bivalve Collections Using Qualitative and Quantitative Methods in the UMR, 1988-99

Pool	RM	Year	No. of Quantitative Samples	No. of Qualitative Samples	No. of Bucket Samples
24	299.6	1988	10	18	--
		1989	60	42	--
		1990	--	--	--
		1991	60	24	--
		1992	--	12	10
		1993	--	--	--
		1994	60	24	--
		1999	60	36	--
17	450.4	1988	20	27	--
		1989	--	--	--
		1990	60	32	--
		1991	--	--	--
		1992	60	24	--
		1993	--	--	--
		1994	60	48	--
14	504.8	1988	20	27	--
		1989	60	59	--
		1990	--	--	--
		1991	60	48	--
		1992	60	36	--
		1993	--	--	--
		1994	60	48	--
		1996	60	14	--
		1999	60	6	
12	571.5	1988	--	--	--
		1989	--	33	--
		1990	60	36	--
		1991	--	--	--
		1992	60	36	--
		1993	--	--	--
		1994	60	36	--
10	635.2	1988	--	43	--
		1989	40	14	--
		1990	--	--	--
		1991	60	48	--
		1992	--	24	40
		1993-MC	60	24	--
		1993-EC	60	60	--
		1994	60	--[1]	--
		1999	60	24	

Note: High water in 1993 eliminated all sampling except in Pool 10. EC = East channel; MC = Main channel. In 1992, mussels were obtained at some sites by collecting total substratum without the 0.25-m^2 quadrats (= bucket samples).
[1] No qualitative samples were collected in 1994 at this location. Instead, a total of 43 separate samples were collected with a suction dredge at a nearshore site in the main channel, two sites in the turning basin of the east channel, and a single site at the reference site in the east channel.

Appendix B
Results of Qualitative Searches for Mussels at Three Locations in the Upper Mississippi River, 1999

Table B1
Percent Abundance of Freshwater Mussels Collected Using Qualitative Methods at Nearshore (Waypoint 12) and Farshore (Waypoint 13) Sites in the Main Channel, UMR, near Prairie du Chien, WI, 1999

Species	Waypoint		Total
	12	13	
A. plicata	59.60	64.29	62.01
M. nervosa	9.60	5.71	7.60
Q. quadrula	4.04	8.57	6.37
L. recta	6.57	3.33	4.90
L. ovata	4.04	2.86	3.43
F. flava	4.04	1.43	2.70
E. dilatata	3.03	1.90	2.45
A. confragosus	1.52	2.86	2.21
Q. pustulosa	1.01	2.86	1.96
L. higginsi	2.53	0.95	1.72
L. fragilis	1.01	0.95	0.98
P. syntoxia	0.51	1.43	0.98
L. complanata	1.01	0.48	0.74
A. suborbiculata	1.52	0.00	0.74
P. grandis	0.00	0.95	0.49
O. reflexa	0.00	0.95	0.49
P. alatus	0.00	0.48	0.25
Total species	14	16	17
Total Individuals	198	210	408
Total time, min		180	
CPUE[1]		1.67	

[1] CPUE = collected per unit effort, or mussels taken per minute of search time.

Table B2
Percent Abundance of Freshwater Mussels Collected Using Qualitative Methods in Pool 14, UMR, 1999

Species	Waypoint Number						Total
	21	22	23	24	25	26	
A. plicata	22.73	29.51	45.31	48.74	57.58	16.67	43.09
L. recta	18.18	11.48	10.16	10.08	0.00	16.67	10.03
Q. quadrula	18.18	9.84	12.50	6.72	0.00	0.00	9.21
M. nervosa	22.73	11.48	5.47	1.68	21.21	50.00	8.40
L. cardium	4.55	11.48	7.03	10.92	0.00	0.00	8.13
Q. pustulosa	0.00	8.20	7.03	10.08	0.00	0.00	7.05
L. complanata	0.00	6.56	2.34	1.68	12.12	16.67	3.79
L. higginsi	0.00	3.28	3.13	0.84	6.06	0.00	2.44
P. grandis	9.09	0.00	2.34	2.52	0.00	0.00	2.17
F. flava	0.00	1.64	3.13	1.68	0.00	0.00	1.90
Q. nodulata	0.00	0.00	0.00	3.36	0.00	0.00	1.08
A. confragosus	4.55	3.28	0.00	0.00	0.00	0.00	0.81
A. ligamentina	0.00	0.00	0.78	0.84	3.03	0.00	0.81
E. lineolata	0.00	0.00	0.00	0.84	0.00	0.00	0.27
L. fragilis	0.00	1.64	0.00	0.00	0.00	0.00	0.27
O. olivaria	0.00	0.00	0.78	0.00	0.00	0.00	0.27
O. reflexa	0.00	1.64	0.00	0.00	0.00	0.00	0.27
Total individuals	22	61	128	119	33	6	369
Total species	7	12	12	13	5	4	17

Table B3
Percent Abundance of Freshwater Mussels Collected Using Qualitative Methods in Pool 24, RM 299.6, Waypoints 28–33, UMR, 1999

Species	Waypoint Number						
	28	29	30	31	None	32	33
E. lineolata	27.23	19.23	11.11	35.00	36.00	32.26	53.97
A. plicata	27.72	19.23	44.44	35.00	28.00	24.19	22.22
O. reflexa	24.26	3.85	22.22	5.00	20.00	8.06	9.52
Q. Quadrula	9.90	3.85	0.00	0.00	0.00	4.84	1.59
O. olivaria	4.46	7.69	0.00	10.00	0.00	12.90	1.59
Q. p. pustulosa	3.47	3.85	11.11	10.00	4.00	6.45	3.17
M. nervosa	0.99	11.54	0.00	0.00	0.00	3.23	3.17
L. fragilis	0.00	3.85	0.00	0.00	4.00	3.23	0.00
F. flava	0.00	0.00	0.00	0.00	0.00	3.23	0.00
L. ovata	0.00	19.23	11.11	5.00	4.00	0.00	3.17
Q. metanevra	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q. nodulata	0.99	0.00	0.00	0.00	0.00	0.00	0.00
L. recta	0.50	3.85	0.00	0.00	4.00	0.00	0.00
T. truncata	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A. confragosus	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C. fluminea	0.50	0.00	0.00	0.00	0.00	0.00	0.00
F. ebena	0.00	0.00	0.00	0.00	0.00	1.61	0.00
L. teres	0.00	0.00	0.00	0.00	0.00	0.00	1.59
P. alatus	0.00	3.85	0.00	0.00	0.00	0.00	0.00
Total time, min	60	60	60	60	60	60	60
Total individuals	202	26	9	20	25	62	63
Total species	10	11	5	6	7	10	9
CPUE[1]	3.37	0.43	0.15	0.33	0.42	1.03	1.05

[1] CPUE = collected per unit effort, or mussels taken per minute of search time.

Table B4
Percent Abundance of Freshwater Mussels Collected Using Qualitative Methods in Pool 24, RM 299.6, Waypoints 34-38, UMR, 1999

Species	Waypoint Number					Total
	34	35	36	37	38	
E. lineolata	55.74	43.14	42.22	30.57	19.26	31.80
A. plicata	11.48	25.49	33.33	27.17	44.81	30.46
O. reflexa	6.56	9.80	7.78	17.74	15.93	15.06
Q. quadrula	4.92	3.92	3.33	9.06	4.44	5.94
O. olivaria	3.28	5.88	3.33	2.26	1.48	3.60
Q. p. pustulosa	1.64	2.94	1.11	4.15	3.33	3.60
M. nervosa	4.92	3.92	6.67	0.75	2.96	2.68
L. fragilis	6.56	1.96	0.00	2.26	1.48	1.67
F. flava	0.00	0.00	0.00	3.02	1.48	1.17
L. ovata	1.64	1.96	0.00	0.00	0.37	1.17
Q. metanevra	0.00	0.00	1.11	1.13	2.59	0.92
Q. nodulata	0.00	0.98	0.00	1.13	0.74	0.67
L. recta	1.64	0.00	1.11	0.00	0.37	0.50
T. truncata	1.64	0.00	0.00	0.75	0.37	0.33
A. confragosus	0.00	0.00	0.00	0.00	0.37	0.08
C. fluminea	0.00	0.00	0.00	0.00	0.00	0.08
F. ebena	0.00	0.00	0.00	0.00	0.00	0.08
L. teres	0.00	0.00	0.00	0.00	0.00	0.08
P. alatus	0.00	0.00	0.00	0.00	0.00	0.08
Total time, min	60	60	60	60	60	720
Total individuals	61	102	90	265	270	1195
Total species	11	10	9	12	15	19
CPUE[1]	1.02	1.70	1.50	4.42	4.50	1.66

[1] CPUE = collected per unit effort, or mussels taken per minute of search time.

Appendix C
Results of Total Substratum Quantitative Samples for Mussels at Three Locations in the Upper Mississippi River, 1999

Table C1
Percent Abundance of Freshwater Mussels Collected Using Quantitative Methods in the Main Channel, UMR, Pool 10, RM 635.5, July 1999

Species	Nearshore, WP 16			Farshore, WP 17			Total
	1	2	3	4	5	6	
A. plicata	71.05	63.64	66.67	86.96	66.67	67.74	70.37
M. nervosa	5.26	9.09	12.50	0.00	8.33	3.23	6.17
L. recta	7.89	4.55	4.17	0.00	0.00	6.45	4.32
E. dilatata	0.00	4.55	4.17	4.35	4.17	6.45	3.70
F. flava	5.26	4.55	0.00	0.00	4.17	0.00	2.47
S. undulatus	2.63	0.00	4.17	0.00	0.00	3.23	1.85
Q. pustulosa	0.00	0.00	0.00	4.35	4.17	3.23	1.85
Q. quadrula	2.63	0.00	4.17	0.00	4.17	0.00	1.85
L. cardium	0.00	9.09	0.00	0.00	0.00	0.00	1.23
O. reflexa	0.00	4.55	0.00	0.00	4.17	0.00	1.23
P. coccineum	0.00	0.00	0.00	0.00	4.17	3.23	1.23
L. fragilis	2.63	0.00	4.17	0.00	0.00	0.00	1.23
A. ligamentina	0.00	0.00	0.00	0.00	0.00	3.23	0.62
L. higginsi	2.63	0.00	0.00	0.00	0.00	0.00	0.62
A. confragosus	0.00	0.00	0.00	0.00	0.00	3.23	0.62
L. siliquoidea	0.00	0.00	0.00	4.35	0.00	0.00	0.62
Total individuals	38	22	24	23	24	31	162
Total species	8	8	7	4	8	9	16
% Species < 30 mm							6.25
% Individuals < 30 mm							0.62
Species diversity							1.33
Evenness							0.48
Menhinick's index							1.26

Note: There were three subsites in the nearshore (1, 2, and 3) and in the farshore (4, 5, and 6) locations (WP = Waypoint).

Table C2
Percent Frequency of Occurrence of Freshwater Mussels Collected Using Quantitative Techniques in the Main Channel, UMR, Pool 10, RM 635.5, July 1999

Species	Nearshore, WP 16			Farshore, WP 17			Total
	1	2	3	4	5	6	
A. plicata	100	60	70	80	60.00	90	76.67
M. nervosa	20	10	30	0	20	10	15.00
L. recta	30	10	10	0	0	20	11.67
E. dilatata	0	10	10	10	10	20	10.00
F. flava	20	10	0	0	10	0	6.67
S. undulatus	10	0	10	0	0	10	5.00
Q. pustulosa	0	0	0	10	10	10	5.00
Q. quadrula	10	0	10	0	10	0	5.00
L. cardium	0	20	0	0	0	0	3.33
O. reflexa	0	10	0	0	10	0	3.33
P. coccineum	0	0	0	0	10	10	3.33
L. fragilis	10	0	10	0	0	0	3.33
A. ligamentina	0	0	0	0	0	10	1.67
L. higginsi	10	0	0	0	0	0	1.67
A. confragosus	0	0	0	0	0	10	1.67
L. siliquoidea	0	0	0	10	0	0	1.67
Total samples	10	10	10	10	10	10	60

Note: There were three subsites in the nearshore (1, 2, and 3) and the farshore (4, 5, and 6) locations (WP = Waypoint).

Table C3
Percent Abundance of Freshwater Mussels Collected Using Quantitative Methods, UMR, Pool 14, RM 505.5, July 1999

Species	Nearshore, WP 21			Farshore, WP 22			Total
	1	2	3	4	5	6	
A. plicata	0.00	50.00	0.00	50.00	0.00	0.00	33.33
Q. quadrula	0.00	0.00	50.00	25.00	0.00	0.00	22.22
M. nervosa	0.00	0.00	0.00	25.00	100.00	0.00	22.22
L. complanata	0.00	50.00	50.00	0.00	0.00	0.00	22.22
Total individuals	0	2	2	4	1	0	9
Total species	0	2	2	3	1	0	4
% Individuals < 30 mm							0.00
% Species < 30 mm							0.00
Species diversity							1.37
Evenness							0.99
Menhinick's index							1.33

Note: There were three subsites in the nearshore (1, 2, and 3) and the farshore (4, 5, and 6) locations (WP = Waypoint).

Table C4
Percent Frequency of Occurrence of Freshwater Mussels Collected Using Quantitative Methods, UMR, Pool 14, RM 505.5, July 1999

Species	Nearshore, WP 21			Farshore, WP 22			Total
	1	2	3	4	5	6	
A. plicata	0.00	10.00	0.00	10.00	0.00	0.00	3.33
Q. quadrula	0.00	0.00	10.00	10.00	0.00	0.00	3.33
M. nervosa	0.00	0.00	0.00	10.00	10.00	0.00	3.33
L. complanata	0.00	10.00	10.00	0.00	0.00	0.00	3.33
Total samples	10	10	10	10	10	10	60

Note: There were three subsites in the nearshore (1, 2, and 3) and the farshore (4, 5, and 6) locations (WP = Waypoint).

Table C5
Percent Abundance of Freshwater Mussels Collected Using Quantitative Methods, UMR, Pool 24, RM 299.6, July 1999

Species	Nearshore, WP 27			Farshore, WP 28 & 32			Total
	1	2	3	4	5	6	
A. plicata	0.00	33.33	20.00	24.56	22.22	45.45	26.77
O. reflexa	100.00	0.00	16.00	21.05	22.22	22.73	21.26
E. lineolata	0.00	0.00	28.00	15.79	44.44	13.64	21.26
O. olivaria	0.00	0.00	16.00	8.77	0.00	9.09	8.66
Q. quadrula	0.00	33.33	0.00	14.04	0.00	0.00	7.09
L. fragilis	0.00	33.33	0.00	5.26	0.00	4.55	3.94
Q. pustulosa	0.00	0.00	8.00	1.75	0.00	0.00	2.36
L. cardium	0.00	0.00	0.00	1.75	5.56	0.00	1.57
M. nervosa	0.00	0.00	4.00	1.75	0.00	0.00	1.57
F. flava	0.00	0.00	0.00	1.75	5.56	0.00	1.57
T. truncata	0.00	0.00	4.00	1.75	0.00	0.00	1.57
Q. nodulata	0.00	0.00	0.00	1.75	0.00	0.00	0.79
L. recta	0.00	0.00	0.00	0.00	0.00	4.55	0.79
T. donaciformis	0.00	0.00	4.00	0.00	0.00	0.00	0.79
Total individuals	2	3	25	57	18	22	127
Total species	1	3	8	12	5	6	14
% Individuals < 30 mm							6.30
% Species < 30 mm							35.70
Species diversity							2.00
Evenness							0.76
Menhinick's index							1.24

Note: There were three subsites in the nearshore (1, 2, and 3) and the farshore (4, 5, and 6) locations (WP = Waypoint).

Table C6
Percent Frequency of Occurrence of Freshwater Mussels Collected Using Quantitative Methods, UMR, Pool 24, RM 299.6, July 1999

Species	Nearshore, WP 30			Farshore, WP 28 & 32			Total
	1	2	3	4	5	6	
A. plicata	0.00	10.00	30.00	80.00	30.00	60.00	35.00
O. reflexa	20.00	0.00	30.00	70.00	40.00	50.00	35.00
E. lineolata	0.00	0.00	50.00	60.00	40.00	20.00	28.33
O. olivaria	0.00	0.00	30.00	40.00	0.00	20.00	15.00
Q. quadrula	0.00	10.00	0.00	50.00	0.00	0.00	10.00
L. fragilis	0.00	10.00	0.00	30.00	0.00	10.00	8.33
Q. pustulosa	0.00	0.00	20.00	10.00	0.00	0.00	5.00
L. cardium	0.00	0.00	0.00	10.00	10.00	0.00	3.33
M. nervosa	0.00	0.00	10.00	10.00	0.00	0.00	3.33
F. flava	0.00	0.00	0.00	10.00	10.00	0.00	3.33
T. truncata	0.00	0.00	10.00	10.00	0.00	0.00	3.33
Q. nodulata	0.00	0.00	0.00	10.00	0.00	0.00	1.67
L. recta	0.00	0.00	0.00	0.00	0.00	10.00	1.67
T. donaciformis	0.00	0.00	10.00	0.00	0.00	0.00	1.67
Total samples	10	10	10	10	10	10	60

Note: There were three subsites in the nearshore (1, 2, and 3) and the farshore (4, 5, and 6) locations (WP = Waypoint).

Appendix D
Presence of Freshwater Mussels at Three Locations in the Upper Mississippi River, 1988-1999

Table D1
Bivalves Collected at RM 635.2, Main Channel, Pool 10, UMR, 1988-1999

Species	1988	1989	1991	1992	1993	1994	1999
Actinonaias ligamentina	x		x		x	x	x
Amblema plicata	x	x	x	x	x	x	x
Anodonta suborbiculata							x
Arcidens confragosus	x	x	x		x	x	x
Cumberlandia monodonta							
Ellipsaria lineolata	x		x		x	x	
Elliptio dilatata	x	x	x	x	x	x	x
Fusconaia ebena							
Fusconaia flava	x	x	x	x	x	x	x
Lampsilis cardium[1]	x	x	x	x	x	x	x
Lampsilis higginsi	x	x	x	x	x	x	x
Lampsilis siliquoidea			x		x		x
Lampsilis teres						x	
Lasmigona c. complanata	x	x			x		x
Lasmigona costata							
Leptodea fragilis	x	x	x	x	x	x	x
Ligumia recta	x	x	x	x	x	x	x
Megalonaias nervosa[2]	x	x	x	x	x	x	x
Obliquaria reflexa	x	x	x	x	x	x	x
Obovaria olivaria	x	x	x		x	x	
Plethobasus cyphyus							
Pleurobema coccineum	x				x		x
Potamilus alatus	x	x	x	x	x	x	x
Potamilus ohiensis		x		x			
Pyganodon grandis[3]	x	x	x	x	x	x	x
Quadrula metanevra	x	x	x	x	x	x	
Quadrula nodulata	x	x	x		x	x	
Quadrula p. pustulosa	x	x	x	x	x	x	x
Quadrula quadrula	x	x	x	x	x	x	x
Strophitus undulatus	x		x	x	x	x	x
Toxolasma parvus	x		x				
Truncilla donaciformis	x	x	x	x	x	x	
Truncilla truncata	x	x	x	x	x	x	
Utterbackia imbecillis[4]	x	x	x			x	
Total individuals – Quantitative	845	874	861		905	680	162
Total individuals - Qualitative	699	212	690	376	404	451	408
Total collected	1544	1086	1551	376	1309	1131	
Total species	27	22	25	18	26	25	

In previous reports these species were occasionally referred to as:

1 Either *L. ovata* or *L. ventricosa.*

2 *Megalonaias gigantea.*

3 *Anodonta grandis.*

4 *Anodonta imbecillis.*

Table D2
Bivalves Collected at RM 504.8, Pool 14, UMR, 1988-99

Species	1988	1989	1991	1992	1994	1999
Actinonaias ligamentina	x					x
Amblema plicata	x	x	x	x	x	x
Arcidens confragosus	x	x	x	x	x	X
Cumberlandia monodonta						
Ellipsaria lineolata	x	x	x	x	x	x
Elliptio dilatata		x	x		x	
Fusconaia ebena						
Fusconaia flava	x	x	x	x	x	X
Lampsilis cardium[1]	x	x	x	x	x	X
Lampsilis higginsi	x	x	x	x	x	X
Lampsilis siliquoidea						
Lampsilis teres						
Lasmigona c. complanata	x	x	x	x	x	x
Lasmigona costata		x				
Leptodea fragilis	x	x	x	x	x	x
Ligumia recta	x	x	x	x	x	x
Megalonaias nervosa[2]	x	x	x	x	x	x
Obliquaria reflexa	x	x	x	x	x	X
Obovaria olivaria	x	x	x	x	x	X
Plethobasus cyphyus						
Pleurobema coccineum						
Potamilus alatus	x	x	x	x	x	
Potamilus ohiensis		x				
Pyganodon grandis[3]	x	x	x	x	x	X
Quadrula metanevra	x	x	x	x	x	
Quadrula nodulata	x	x	x	x	x	X
Quadrula pustulosa	x	x	x	x	x	X
Quadrula quadrula	x	x	x	x	x	X
Strophitus undulatus			x			
Toxolasma parvus	x	x				
Truncilla donaciformis	x	x	x		x	
Truncilla truncata	x	x	x	x	x	
Utterbackia imbecillis[4]	x		x		x	
Total individuals - Quantitative	253	919	1,247		903	9
Total individuals - Qualitative	734	961	815	386	789	369
Total collected	987	1,880	2,062	386	1,692	378
Total species	24	24	24	19	23	

In previous reports these species were occasionally referred to as:

1 Either *L. ovata* or *L. ventricosa.*

2 *Megalonaias gigantea.*

3 *Anodonta grandis.*

4 *Anodonta imbecillis.*

Table D3
Bivalves Collected at RM 299.6, Pool 24, UMR, 1988-99

Species	1988	1989	1991	1992	1994	1999
Actinonaias ligamentina				x		
Amblema plicata	x	X	x	x	x	x
Arcidens confragosus		X	x		x	x
Cumberlandia monodonta		X				
Ellipsaria lineolata	x	X	x	x	x	x
Elliptio dilatata						
Fusconaia ebena	x		x			x
Fusconaia flava	x	X	x	x	x	x
Lampsilis cardium[1]	x	X	x	x	x	x
Lampsilis higginsi						
Lampsilis siliquoidea						
Lampsilis teres					x	x
Lasmigona complanata		X	x		x	
Lasmigona costata						
Leptodea fragilis	x	X	x		x	x
Ligumia recta	x	X	x		x	x
Megalonaias nervosa[2]	x	X	x	x	x	x
Obliquaria reflexa	x	X	x	x	x	x
Obovaria olivaria	x	X	x	x	x	x
Plethobasus cyphyus						
Pleurobema coccineum						
Potamilus alatus	x	X	x		x	x
Potamilus ohiensis						
Pyganodon grandis[3]		x	x			
Quadrula metanevra	x	x	x	x	x	x
Quadrula nodulata	x	x	x	x	x	x
Quadrula pustulosa	x	x	x	x	x	x
Quadrula quadrula	x	x	x	x	x	x
Strophitus undulatus						
Toxolasma parvus						
Truncilla donaciformis	x	x	x		x	x
Truncilla truncata	x	x	x	x	x	x
Utterbackia imbecillis[4]		x	x			
Total individuals - Quantitative	78	1,143	301		243	127
Total individuals - Qualitative	326	648	465	184	390	1195
Total collected	404	1,791	766	184	633	1372
Total species	18	22	22	13	20	

In previous reports these species were occasionally referred to as:
1 Either *L. ovata* or *L. ventricosa*.
2 *Megalonaias gigantea*.
3 *Pyganodon grandis*.
4 *Utterbackia imbecillis*.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE (*DD-MM-YYYY*)	2. REPORT TYPE	3. DATES COVERED (*From - To*)
September 2002	Final report	

4. TITLE AND SUBTITLE

Effects of Increased Commercial Navigation Traffic on Freshwater Mussels in the Upper Mississippi River: Ten-Year Evaluation

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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Environmental Laboratory
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER

ERDC/EL TR-02-32

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Engineer District, St. Louis
St. Louis, MO 63103-2833

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

In the late 1980s the U.S. Army Engineer District, St. Louis, requested that the U.S. Army Engineer Waterways Experiment Station, now part of the Engineer Research and Development Center, in Vicksburg, MS, conduct studies on the physical and biological effects of commercial navigation traffic at five historically prominent mussel beds in the upper Mississippi River (UMR). The purpose was to assess effects of increased navigation traffic caused by the newly completed Melvin Price Locks and Dam at Alton, IL. Studies were initiated in 1989 and conducted annually until 1994 when they were to be done every fifth year until 2040. This report describes results of studies conducted in 1999 at three of the mussel beds located in Pool 10 (River Mile (RM) 635), Pool 14 (RM 504.8), and Pool 24 (RM 299.6). In previous years, mussel beds at RM 450.4 (Pool 17) and RM 571.5 (Pool 12) were also studied. Because of recent concern over effects of zebra mussels (*Dreissena polymorpha*) on freshwater mussels, data collected in 2000 and 2001 on this species have also been included.

(*Continued*)

15. SUBJECT TERMS

Freshwater mussels
Navigation traffic
Upper Mississippi River

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (*include area code*)
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED		61	

14. (Concluded).

In 1999, 26 species of bivalves, including the Asian clam, *Corbicula fluminea,* were collected at the three beds in the UMR using qualitative methods. Overall, the fauna was dominated by *Amblema plicata*; this species comprised more than 60 and 40 percent of the fauna in Pools 10 and 14, respectively. *Ellipsaria lineolata* was the dominant freshwater mussel at the mussel bed in Pool 24. The endangered *Lampsilis higginsi* was found in Pool 10 (1.72 percent of the assemblage) and Pool 14 (2.44 percent of the assemblage). It was not found in Pool 24, which is outside its range.

Using quantitative methods, a total of nearly 300 individuals and 23 species of mussels were collected at the three locations in the UMR in 1999. Mean total density (individuals/m^2) varied from a low of 0.6 (standard deviation = 1.9) at the bed in Pool 14, to a high of 10.8 (standard deviation = 7.6) at the bed in Pool 10. These density values are considerably lower than at these locations in previous years. Based upon 1999 data, it was concluded that there were no changes in numbers of *L. higginsi*, or the total number of species present at these beds. There were, however, significant changes in total mean mussel density, ratios of live-to-dead mussels, and evidence of recent recruitment for common species. These changes were not caused by commercial navigation traffic, which has changed little in the past 10 years, but rather to introduction and spread of *D. polymorpha.* In Pool 10 of the UMR, *D. polymorpha* densities have been at or near approximately 10,000 individuals/m^2 since 1996.